Western Australian School of Mines

Department of Applied Geology

Geological Controls on the Distribution of Arsenic in the Perseverance Nickel Deposit, Leinster, WA

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To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Alexandre Albiero Diragitch

Date 29/11/2014

ABSTRACT

The Perseverance deposit is a highly deformed ultramafic disseminated and semi-massive sulphide orebody, resulting in significant mobilization of primary magmatic sulphide ores into axial planar shear zones that have been subsequently refolded (Barnes et al 2011 and references therein). The bulk of the Perseverance orebody comprises a basal accumulation of matrix ores (heavily disseminated sulphide mineralisation), occupying an arcuate channel feature, with an extensive asymmetric halo of disseminated sulphides. The Perseverance Ultramafic Complex (PUC) is interpreted as a high-flux, flow-through conduit formed by evolving magmas and there is a pervasive signature of country-rock contamination throughout the complex (Barnes et al, 2011).

The most common arsenic-bearing minerals in the Perseverance deposit are Co-Ni-Fe sulpharsenide phases, Gersdorffite (NiAsS) and Cobaltite (CoAsS). High arsenic concentrations within main Perseverance orebody were previously known in the massive sulphide ore shoots and along the footwall massive sulphide rocks in areas with intense shear zones. The main matrix sulphide mineralisation was considered previously as an essentially arsenic “free” mineralisation, however, based on this study, it has been confirmed that the arsenic zone is not only confined to the remobilized massive sulphides, it is also found within the main matrix and heavily disseminated sulphide ore of PUC, with samples reaching excess of over 50,000ppm As (total whole rock analyses).

Arsenic-bearing minerals within the PUC are found within: olivine-tremolite-chlorite rocks containing carbonate, which correspond to metamorphosed komatiite flows, with the variation in present olivine content reflecting an original alternation between spinifex textured A zones and olivine-enriched cumulate B-zones; massive sulphides (which includes massive sulphides with brecciated rocks); matrix and disseminated sulphide olivine-cumulate rocks containing carbonates; the PUC basal contact unit, which formed within a mylonitic zone; and a serpentinised olivine-cumulate rock, located at the basal portion of the PUC.

Cobaltite is interpreted to have minimum crystallisation temperatures between 500ºC to 550ºC. Gersdorffite has a wider crystallisation temperature range, with an interpreted minimum crystallisation temperature estimated from approximately 250ºC to 550ºC. Arsenic-bearing minerals whose minimum crystallisation temperature lies at approximately 550ºC are inferred to be associated with the

peak metamorphic event, with lower minimum temperatures recording remobilisation by later retrograde events.

The arsenic source and its influx into the Perseverance Ultramafic Complex remains unclear, and it may realistically be linked to any of the events from magmatism to peak metamorphism, including early serpentinisation and talc-carbonate alteration prior to the de-hydration reactions that occurred during peak metamorphism. Evidence of the earlier (magmatic and/or early alteration) processes is now overprinted by the ubiquitous metamorphic and metasomatic events throughout the study area.

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Some of the ideas and geological knowledge of this project rely on works developed by previous geologists from BHP Billiton, Western Mining Corporation and academic researchers. Their work during the long history of the Perseverance Nickel Deposit is acknowledged here.

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1. INTRODUCTION

Arsenic (As) is currently regarded as one of the most toxic inorganic pollutants, causing environmental and health impacts in several areas of the world (Lengke et al, 2009). Arsenic is carcinogenic and has been linked to a variety of skin diseases, and can damage the nervous and digestive systems (Lengke et al, 2009). It is also a contaminant in nickel ore, especially if nickel metal is used in the steel industry as an important component in stainless steel (Davies, 1996). Arsenic can cause steel to become brittle, which has an effect on the quality of steel products. Its removal from the nickel metal is expensive and leaves a toxic waste (Davies, 1996)

This study focusses on the Perseverance nickel deposit (formerly Agnew nickel deposit), which is located 15 km north of Leinster and 380 km north of Kalgoorlie, Western Australia (Figure 1.1). It was an underground mine and ore deposit, and is currently under care and maintenance at the Leinster Nickel Operations of BHP Billiton. The deposit used to be a source of nickel concentrate due to its high and constant quality of nickel grade, excellent Mg/Fe ratio, and low quantities of impurities and contaminants, except for arsenic, which is detrimental in the steel production process.

The Perseverance deposit is highly deformed. Deformation resulted in significant mobilization of primary magmatic sulphide ores into axial planar shear zones that are subsequently refolded (Barnes et al 2011). The bulk of the Perseverance orebody comprises a basal accumulation of matrix ores (heavily disseminated sulphide ore) that occupy an arcuate channel feature, with an extensive asymmetric halo of disseminated sulphides. The host rocks display a complex metamorphic history involving multiple episodes of hydration, carbonation, dehydration, decarbonation, and retrograde alteration (Barnes et al 2011).

The majority of the Ni mineralisation is almost free of contaminants, especially arsenic. However, some sections of the Perseverance ore body are anomalously enriched in arsenic, which is reported to be present mainly as gersdorffite, NiAsS (Davies, 1996). Arsenic concentration is generally relatively low (less than 50 ppm) within the unaltered magmatic nickel sulphide deposits, but where mineralisation has been subject to metamorphism and hydrothermal alteration the arsenic

concentrations can increase significantly (De-Vitry, 1999). Also, most of the sulpharsenides present in the study area are intimately associated with nickel, so the Ni-As association can have an adverse effect on nickel production downstream.

The aim of this study is to gain an improved understanding of the geological controls on As distribution. This understanding may help to make a more comprehensive assessment of arsenic distribution at Perseverance and assist in the evaluation of similar deposits nearby.

1.1. Location and Access

The Perseverance Nickel deposit is located 15 km north of Leinster, which is approximately 700 km northeast of Perth, the capital of Western Australia, and about 380 km north of Kalgoorlie (Figure 1.1). The Wiluna–Leinster Road, which bypasses Leinster, is sealed from Mount Keith to Kalgoorlie. The road from the Perseverance mine, via Leinster, is sealed to the Wiluna–Leinster Road. Leinster is also linked to Perth via a gravel road from Leinster to Mt Magnet then sealed to Perth along the Great Northern Highway (see Figure 1.1 along corridor from Perth to Meekathara).

1.2. Objective

The objectives of this thesis are to: (1) document the geological setting of As-rich rocks; (2) identify arsenic-host minerals and their textural setting within the main ultramafic komatiite body; (3) to determine controls on the distribution of arsenic in the ore zones of the main Perseverance ultramafic komatiite body and its country rocks, with a focus on the current and future production areas of the deposit, and (4) to determine the processes that affect arsenic distribution.

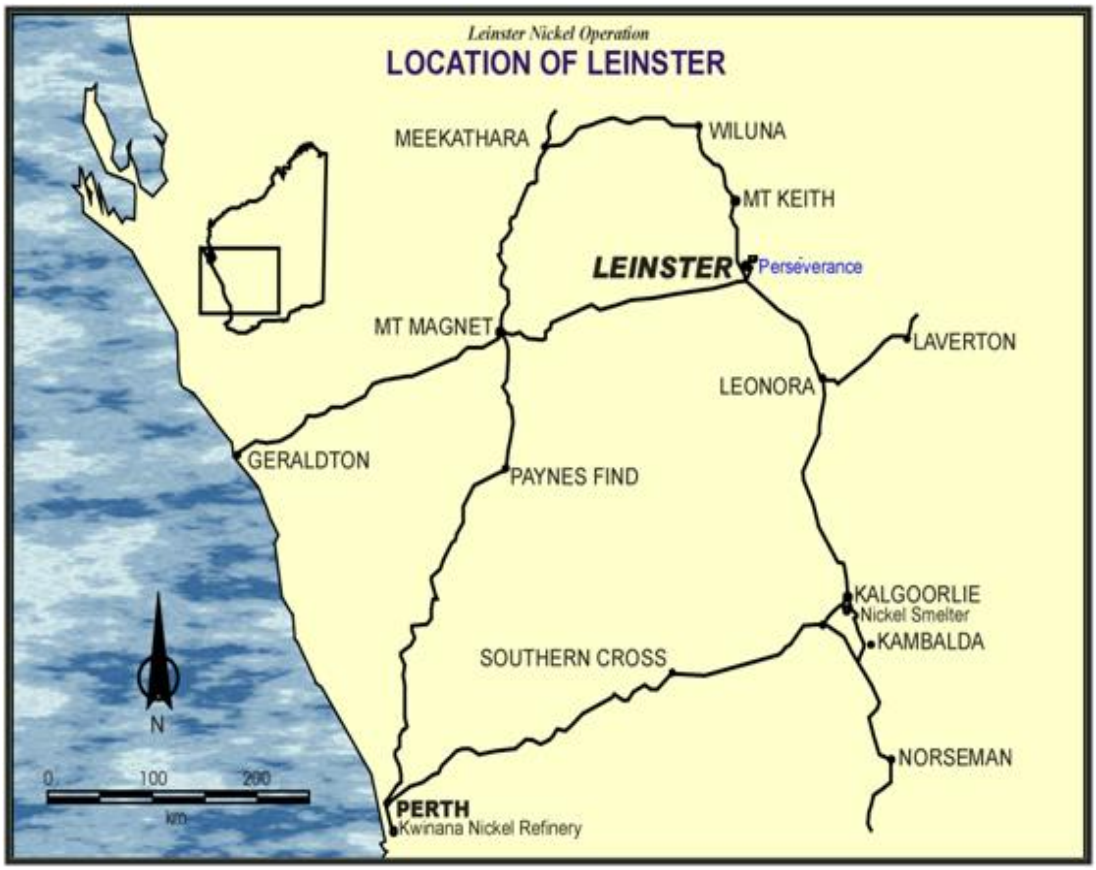


Figure 1.1. - Location of the Perseverance Mine near Leinster, Western Australia and selected access roads (from Corley, 2007).

1.3. Background

Perseverance is a high-grade nickel sulphide deposit with low levels of contaminants. However it does contain areas of significant elevated arsenic. Previous study has shown that the main As-bearing mineral is gersdorffite, and that generally the arsenic-rich zones are located in massive sulphide ore bodies, especially the 1A and F2 deposits, which feature remobilised nickel-iron sulphides in faults and shear zones (Davies, 1996). At deeper levels, accessed by exploration drill holes, detailed in-fill drilling data, and early development underground mine drives, arsenic has been found inside the main ultramafic komatiite body but its source and mineralogy is not fully understood. This project therefore focuses only on the arsenic mineralisation within the main ultramafic komatiite body rather than the remobilised nickel-iron sulphide massive bodies.

The current geological and geostatistical models used at the mine site are based on 50 ppm arsenic break values, which are defined by values higher than 50 ppm of As of the total assay of the in-situ rock. This value was defined based on the

processing parameters from the run of mine (ROM; ore coming from the mine operation) to concentrate product. The deposit has a head grade of 1.8 % Ni and concentration of ~14 % Ni after flotation, the maximum tolerance for arsenic to be fed into the crusher is 50 ppm. If As is higher than 50ppm then the final concentrate from the flotation has an arsenic concentration higher than 400 ppm, since arsenic concentrates in the same way as the nickel grade in the flotation process. An excess of arsenic in the concentrated product negatively affects the products downstream, through the smelter and refinery.

1.4. Research Methodology

This study is based on the petrography, mineralogy, geochemistry and sulphur isotopes of rocks and core samples collected from diamond drillholes and underground mine development drives. Sixty four samples were selected for petrological and mineralogical study. Sixty one of these samples were collected from diamond drill cores and three from mining development face samples (Appendix 1 contains sample details). Forty seven samples were examined by reflected-transmitted light microscopy (RTL), nine samples of the country rocks were examined by transmitted light microscopy (TL) and eight samples were studied by reflected light microscopy (RL). All conventional microscopy study was undertaken using facilities at Curtin University, Department of Applied Geology.

The majority of the samples (samples C01 to C61 and H01 to H03) were assayed by inductively coupled plasma-optical emission spectroscopy (ICP-OES) for Co, Cu and Ni and by X-ray Fluorescence Spectrometry (XRF) for Al_2O_3, As, Cr, Fe, MgO, S, SiO_2, CaO and Cl at the BHP Billiton - Perseverance mine site analytical laboratory. X-ray powder diffraction (XRD) studies were carried out using a PANalytical Cubix – PRO diffractometer with Cu Kα radiation, which was also located at the mine site. Certified reference materials (5 different standard types) were inserted with the sample sequence, equating to approximately 4 % (1:25) of the samples dispatched to the laboratory. In addition blank samples were added and field duplicates were taken representing 2 % (1:50) of the data drillhole dataset (more details in Appendix 1). Sample preparation involved dispatch of half cut diamond drill core or full chip samples from the blasted mine face to the mine site laboratory for initial sorting and drying at 105ºC. Primary preparation included coarse crushing of the entire sample, followed by pulverising in a ring pulveriser to a pulp. Split aliquots were then taken for X-ray Fluorescence (XRF), X–ray

diffraction (XRD) and high accuracy arsenic XRF analyses (Brouwer, 2006). The excess material was discarded after approximately 60 days and the pulp samples were delivered to the core-shed to be stored. All XRF samples, except those for As, were cast using a 12:22 melting flux (12 of sample and 22 of flux base for casting to form a glass bead) and the ICP samples were pre-oxidised, to prevent losses of sulphur, and then digested with a three acid mixture containing hydrofluoric, nitric and perchloric acids. Samples for arsenic assays and XRD were prepared as pressed powder pellets. A detection limit of 0.01 % was applicable for the following: Al_2O_3, Fe_2O_3, MgO, Ni, S, SiO_2 and CaO; 10 ppm for: Co, Cr and Cu; 5 ppm for As and 100 ppm for Cl. XRD detection limits were 1% for any given mineral. The results of the chemical assays, mineral percentages obtained, and additional details for the physical preparation and analysis at the Perseverance Mine Laboratory are listed in Appendix 1.

Mineral composition analysis was undertaken by quantitative Scanning Electron Microscopy (SEM) with Energy Dispersive Spectra (EDS) analysis to identify major and selected trace element concentrations in sulphides and oxides. These data were used as inputs to geothermometric equations in order to estimate temperatures of equilibration of key mineral assemblages. Twenty-six samples were examined and analysed qualitatively by SEM with EDS and back-scattered electron images at Curtin Electron Microscope Laboratories, Dept of Imaging & Applied Physics. From those, twenty-two samples were selected for a quantitative measurement. The composition of the arsenic-bearing minerals and adjacent minerals was determined by energy-dispersive X-ray spectroscopy microanalysis, using a Zeiss Evo 40XVP scanning electron microscope with an attached Oxford Instruments energy dispersive X-ray detector (EDS). Primary metal and mineral standards were used for calibration. Sulphides and oxides were analysed using the following X-ray lines Fe Kα, Co Kα, Ni Kα, Cu Kα, Cr Kα, Sb Kα, Ga Kα, As Kα and S Kα. Elements were calibrated to pure metal standards and natural and synthetic minerals with known compositions where available. The metals standards utilised include: Fe, Co, Ni, Cu and Cr; and mineral standards were used for Sb, Ga, As (GaAs and SbAs) and S (FeS). The operating conditions used were under controlled pressure mode with a chamber pressure of between 0.1 to 0.5 Mbar, accelerating voltage of 20 Kev, beam current of 45 nA, working distance of 8.5 mm, with a counting time of 100 seconds per spectrum (EDS detection limit of 0.01%, precision of 1.0%). Based on the repetitive analysis of the arsenic

standard, a mean of 49.07% of As was obtained for the GaAs standard with two standard deviation of ±0.77% (total of 10 analyses for calibration) and 50% stoichiometric As content in GaAs.

Seven rock samples were selected for sulphur isotope analysis and ten mineral separates were collected from these samples. Five mineral samples were selected from pyrrhotite (3 samples) and pentlandite (2 samples) separates, as these are the most common sulphide minerals at the deposit. Other samples are two less common minerals that are potentially related to later crystallisation of sulphides at the study area (one non-magnetic pyrrhotite, one chalcopyrite) and three samples of sulpharsenide (gersdorffite only). The ten selected mineral samples were crushed in a small jaw crusher followed by hand crushing using a pestle and mortar to liberate the sulphide grains from the matrix. Minerals were then handpicked using a binocular microscope at Curtin University. The selected grains were collected and stored in vials prior to being sent to SIRA Laboratory, Central Science Laboratory, University of Tasmania. Appendix 5 describes the lab procedure and analysis precision. Results are reported and discussed in Chapter 7 (Sulphur Isotopes).

The aims of this project are accomplished by the review of regional and local geology (Chapter 2), Macro distribution of arsenic at the Perseverance deposit (Chapter 3), Sample selection and whole rock data (Chapter 4), Petrology and mineralogy of the Perseverance deposit in the study area (Chapter 5), sulphide, sulpharsenide and oxide compositions (Chapter 6), sulphur isotopes (Chapter 7) and genetic model for arsenic mineralisation and conclusions (Chapter 8).

2. GEOLOGY OF THE PERSEVERANCE DEPOSIT

2.1 Regional Geology - Stratigraphy and Metamorphism

The Perseverance Deposit is located in the Agnew-Wiluna belt, which is the smaller of two greenstone belts in the northern Kalgoorlie Terrane of the Eastern Goldfields Province of the Yilgarn Craton, Western Australia, Barley et al, 2007 (Figure 2.1). The Agnew-Wiluna belt is an Archean belt made up of a ~ 2.7 Ga (Black et al, 2002) sequence of basaltic and felsic volcanic and volcaniclastic rocks, sulphidic carbonaceous shales and volcanogenic exhalites, and multiple intervals of komatiites that include cumulate-rich units and thin spinifex-textured units. It forms the northern third of the Norseman-Wiluna Belt (Barnes et al, 2011), and is inferred to be equivalent to the greenstone sequence in the Kalgoorlie region (Cassidy et al, 2002). The ultramafic units are interpreted to be the time equivalent of the Kambalda ultramafic sequence and define a regional marker horizon (Beresford et al, 2004). The Agnew-Wiluna Belt is a strongly attenuated greenstone belt, which has an hourglass shape and it hosts four of the fifteen largest nickel sulphide resources in the world: Mount Keith, Perseverance, Yakabindie and Honeymoon Well (Figure 2.2) and several of the world's largest komatiite-hosted Ni-Cu sulphide deposits (Beresford et al, 2004).

The Agnew–Wiluna greenstone belt is between 2 and 20 km wide, and over 200 km north–south (Cassidy et al, 2006). It is bounded to the west by the Waroonga-Ballard shear zone, a zone of heterogeneously deformed granitoids, and on the east by the Keith-Kilkenny lineament (Cassidy, 2002), which represents a series of faults (Figure 2.2.). The northernmost part of the belt is concealed by rocks of the overlying Proterozoic Earaheedy Group and by the Marsh domain in the southeast (Barnes et al, 2011). Older greenstone successions are preserved at Wiluna and to the west of Yakabindie and may represent the basement of the mafic-ultramafic sequence (Barnes et al, 2011). The stratigraphy of the Agnew-Wiluna belt is best defined from the Mt Keith domain, which contains the least deformed and most complete stratigraphy. Within this domain there are three multiple ultramafic horizons; the Mt Keith, Cliffs and Monument Ultramafic units, which are interlayered with felsic and mafic rocks, ranging in composition from rhyolite to Mg-rich tholeiitic basalt.

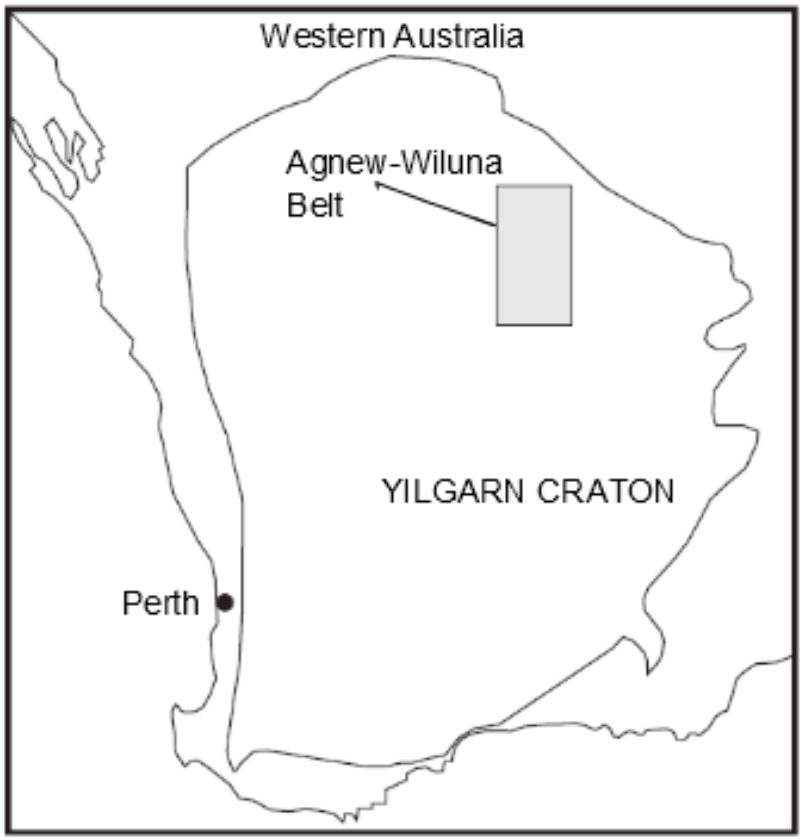


Figure 2.1. - Location map of the Agnew-Wiluna Greenstone belt in the Yilgarn Craton, WA (from Fiorentini et al, 2012). Perseverance deposit is at Leinster, in the northern part of the Eastern Goldfields Province.

The basal unit in the stratigraphy is the McFarlane's basalt, which is present in all domains of the Agnew-Wiluna and is up to 1,000 m in thickness; it displays pillow structures in the Agnew area, and locally is referred to as the Lawlers basalt (Beresford et al, 2004). The intermediate to felsic rocks in the belt range from andesite to rhyolite in composition, with dacite the dominant rock type (Barnes et al, 2011). The Mount Keith dacite is a laterally extensive dacitic volcanic and volcaniclastic unit, present only along the axis of the greenstone belt (Rosengren et al, 2008). Stratigraphically overlying the Mount Keith dacite is the Centenary Bore basalt, which is composed of a high Mg/Fe basalt sequence of tholeiitic affinity intercalated with carbonaceous shales and pyritic cherts (Beresford et al., 2004).

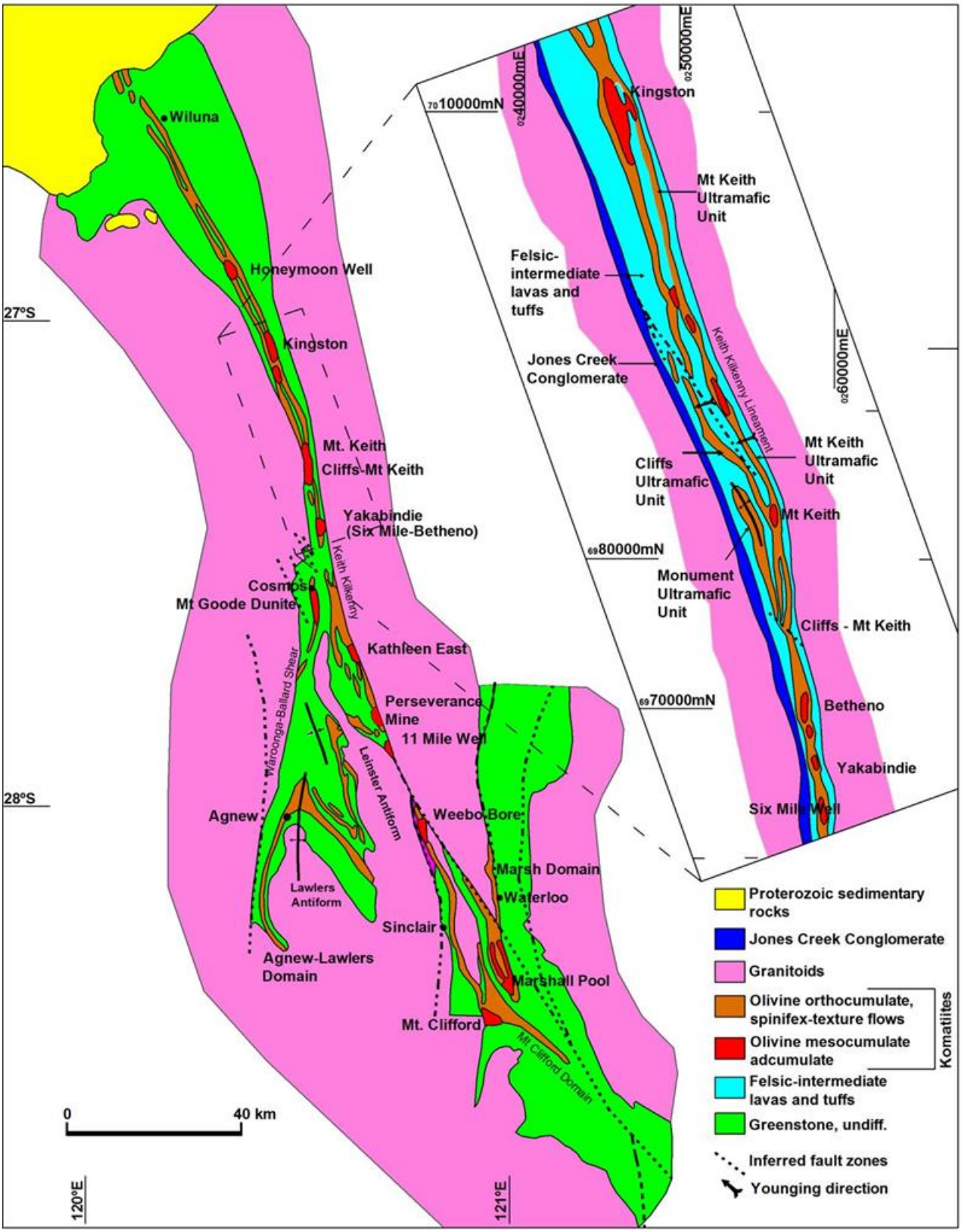


Figure 2.2. - Geological map of the Agnew-Wiluna Belt (modified from Barnes et al, 2011).

The Cliffs unit, overlying the Centenary Bore basalt, is locally more than 300 m thick and consists of a sequence of cumulate-rich channelized sheet flows overlain and flanked by thin differentiated olivine spinifex-textured flow units. This unit contains basal massive nickel sulphide mineralisation at Cliffs and 11 Mile Well (5 km south of Perseverance), Barnes et al (2011). The uppermost komatiite layer in the belt, also best developed at Mount Keith, is the Monument unit, which is a sequence of thin differentiated flows showing typical differentiation zones (Barnes, 2011). The sequence is in fault contact with the Jones Creek Conglomerate, to the west, which is a younger unconformable basin-fill clastic sedimentary unit (Barnes et al, 2011). The metamorphic grade increases from north to south; ranging from prehnite–pumpellyite and lower greenschist facies near Wiluna in the north, through middle-greenschist facies at Mt Keith and up to lower to middle amphibolite facies (<555 ºC) in the Leinster/Perseverance deposit (Gole et al, 1987).

The deformation history of the Agnew-Wiluna Belt is described by a series of regional events from D1 to D4 (Duuring et al, 2004). The earliest preserved deformation event is a regional D1 north-south directed shortening that caused duplication of the stratigraphy by isoclinal recumbent folding and north-over-south reverse fault displacement. East-west shortening during the second deformation event (regional D2) formed NNW-striking, open to tight folds and a well-developed axial planar schistosity. The regional D2 event is expressed by NNW-striking, S-shaped (looking north), asymmetric folds and a pervasive NNW-striking, steeply W-dipping axial planar schistosity (e.g. Leinster antiform). The third regional deformation event (D3) involves north-trending, dextral strike to oblique-slip faulting. D4 shows a stress regime change to an east-southeast and west-northwest orientation causing north-northwest trending, sinistral strike to oblique-slip faults and crenulations. Post-D4 involves late-stage brittle faults cut the ore-bearing stratigraphy in various places. Offsets are generally minor and they may in part relate to last increments of strike-slip dominated movement on the main faults (Duuring et al, 2004).

2.2 Local Geology

Fundamental stratigraphic, petrologic, geochemical and structural relationships at Perseverance have been investigated over the last three decades. The Perseverance Ultramafic Complex (PUC) strikes NNW, dips steeply to the west, and includes an overturned basal nickel sulphide-bearing adcumulate textured komatiite overlain by a thicker dunite lens, which is truncated along its eastern margin. The ultramafic complex is enveloped by mafic to intermediate volcanic and sedimentary country rocks subsequently overlain by E-facing, locally nickel sulphide-bearing and spinifex-textured, komatiite (Duuring et al, 2004).

2.2.1 Lithostratigraphy

The local stratigraphy at Perseverance youngs from west to east, and includes in this order (Figure 2.3 and Figure 2.6):

- mafic to intermediate volcanic and sedimentary footwall rocks and a thinner komatiite unit that occurs to the west of the main ultramafic unit (locally known as undifferentiated footwall sequence);
- a thick ultramafic komatiite body with basal nickel sulphide mineralisation and a hanging wall package (Perseverance Ultramafic Complex – PUC), which includes mafic to intermediate volcanic rocks;
- nickel sulphide-bearing komatiite and sedimentary rocks.

The east-facing stratigraphy has been overturned during diverse deformation events and now it is positioned in cross-section in plan view. To the east of the deposit, the stratigraphy is truncated by the regional NNW-striking Perseverance Fault, which is part of the regional Keith-Kilkenny lineament juxtaposing the stratigraphy against granitoid rocks to the east (Journeaux, 2009).

2.2.1.1 Footwall Rocks

The Footwall rocks, as locally known as undifferentiated “Felsic Rocks”, lie directly to the west of the PUC and in the “Felsic Nose”. They consist of intercalated schistose plagioclase ± quartz porphyry and brecciated to fine-grained biotite-rich sedimentary rocks (Figures 2.3 and 2.5). Calc-silicate pods containing amphibole, biotite, garnet, and titanite in the footwall sequence are interpreted to have formed

during mid-amphibolite facies peak metamorphism in the Leinster area (Duuring et al, 2004).

2.2.1.2 Perseverance Ultramafic Complex

The Perseverance Ultramafic Complex (PUC) comprises a thick, largely intact accumulation of olivine-rich ultramafic lithologies (adcumulate to mesocumulate). The stratigraphic top of the complex is truncated by a major NNW fault, the Perseverance Fault, which juxtaposes orthocumulate-dominant, spinifex-textured komatiite against the granite rocks. Adcumulate to mesocumulate lithologies that comprise the main part of the complex are found below the orthocumulate-dominant zones (Barnes et al, 2011 and shown on Figure 2.3). The PUC rocks are interpreted as having crystallised from komatiitic lavas, and exhibit a spectrum of compositions from those of original flow tops to pure olivine adcumulate (Gole et al, 1987). The ultramafic complex is divided into a central, essentially non-mineralised domain and a western domain of variably mineralised ultramafic rocks along the stratigraphic base of the PUC. The central domain is characterised by a layered succession of coarse-grained (>0.5 cm) olivine adcumulate to mesocumulate komatiite rocks, which has minor amounts of talc and anthophyllite. Although predominantly non-mineralised, there are two narrow zones (up to 10 m wide) of sulphide mineralisation with blebby pentlandite. Interstitial to coarse cumulus olivine occurs within this domain (Job, 2002).

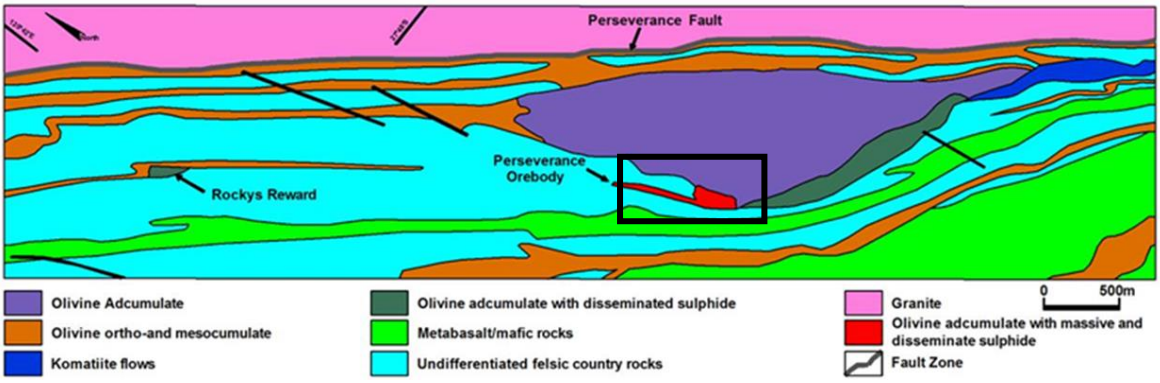


Figure 2.3. - Geological map showing the geology and distribution of the Perseverance nickel sulphide deposit (modified from Barnes et al, 2011). Area in red (Perseverance Orebody) is composed mainly of massive/matrix metamorphic olivine-sulphide adcumulate with minor contents of disseminated metamorphic olivine-sulphide adcumulate. The black box covering part of the Perseverance Orebody, undifferentiated felsic country rocks and metabasalt/mafic rocks illustrates the approximate spatial cover of the study area.

The mineralised western domain forms an extensive sheet up to 2.5 km long with variably mineralised olivine adcumulate to mesocumulate komatiite rocks along the base of the ultramafic complex. The domain is characterized by trace to weakly disseminated sulphide, with heavily disseminated to a semi-massive (net textured) and massive sulphide. Within this domain, systematic variations in the abundance of intercumulus sulphide and the grain size of (ex)olivine grains (now pseudomorphed by serpentine minerals) defines a distinct, laterally continuous mineralised stratigraphy. The domain is thickest (up to 250 m wide) at the Perseverance deposit (Duuring et al, 2004).

2.2.2 Nickel Sulphide Mineralisation

Nickel sulphides at Perseverance mainly occur as disseminated mineralisation along the footwall contact in the ultramafic komatiite rock types and as massive sulphides remobilized into/along shear and fault zones. Mineralised zones are represented by the 1 % Ni cut-off (shown on Figure 2.5), which can be sub-divided into according to its spatial location:

- ➔ Disseminated and semi-massive sulphides hosted in komatiite; this makes up the bulk of the Ni metal contained and can be sub-divided into different local deposits. The Perseverance Sub Level Cave (SLC) or also known as the Main Disseminated Orebody is 100–200 m long, 75–130 m wide and almost 1350 m vertical depth. This is the biggest deposit of PUC (located on Figure 2.5). Other small satellite deposits consist of small pods of disseminated sulphides. This includes the Progress ore body, which is located 200 m to the north of the SLC (Figure 2.5, highlighted as Progress deposit). The biggest Progress pod is approximately 300 m deep, 120 m in length and 15 m in true thickness. The sulphides in the disseminated ore are interstitial to the serpentinised olivine in areas along the basal portion of the main ore body, showing medium to coarse-grained sulphides (especially coarse pentlandite). The disseminated and semi-massive sulphide ore body is defined by a region that contains more than 1% Ni and it contains 5 to 50 % sulphides in total (more details in Chapter 4, Petrography).

- ➔ Massive sulphide layers – these are 0.2 to 5 m thick and located along the basal contact of the komatiite rocks but also along shears and fault zones

(mylonite zone, Figure 2.5) that are both within the ultramafic and footwall rocks. The ore bodies occur to the North and Northwest of the SLC. The 1A ore shoot, located north of SLC (Figure 2.5) is the most extensive and continuous massive sulphide shoot at Perseverance deposit and extends to 100 m to the north of the disseminated sulphide ore body, as a continuation of the hanging wall limb area (Figure 2.5). The F2 massive sulphide ore bodies occur as small lenses close to the footwall contact around the Felsic Nose (Northeast of SLC, now fully mined out, Figures 2.5 and 2.6) they have an average of 7.5% Ni and geometry defined by multiple NNW-striking fault and shear zones, with almost 5 m thickness and 50 m in length.

The primary sulphide mineralogy in areas of disseminated and massive mineralisation of nickel sulphide (basal limit with cut off of 1% Ni, Figure 2.5) consists of mainly pyrrhotite (almost 80% in total) and pentlandite (8-10%). Other less common sulphides are chalcopyrite ($CuFeS_2$) and pyrite (FeS_2). Gersdorffite (NiAsS) and cobaltite (CoAsS) represent the sulpharsenides. Magnetite (Fe_3O_4) and ferri-chromite ($Fe^{2+}(Cr^{3+},Fe^{3+})_2O_4$) are the main oxides present (Rodsjo, 1999).

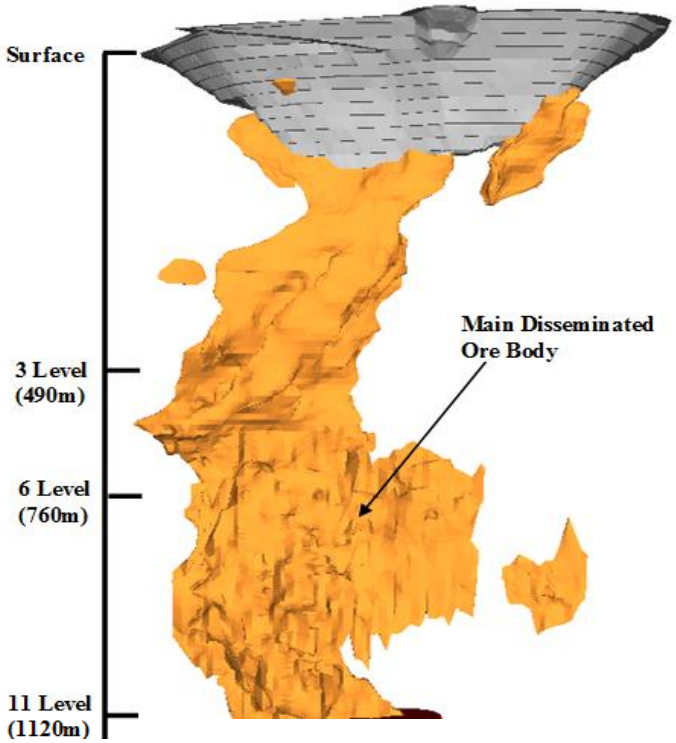


Figure 2.4. - Perspective view of the Perseverance nickel sulphide Main disseminated orebody and main underground mining levels (from Journeaux, 2009).

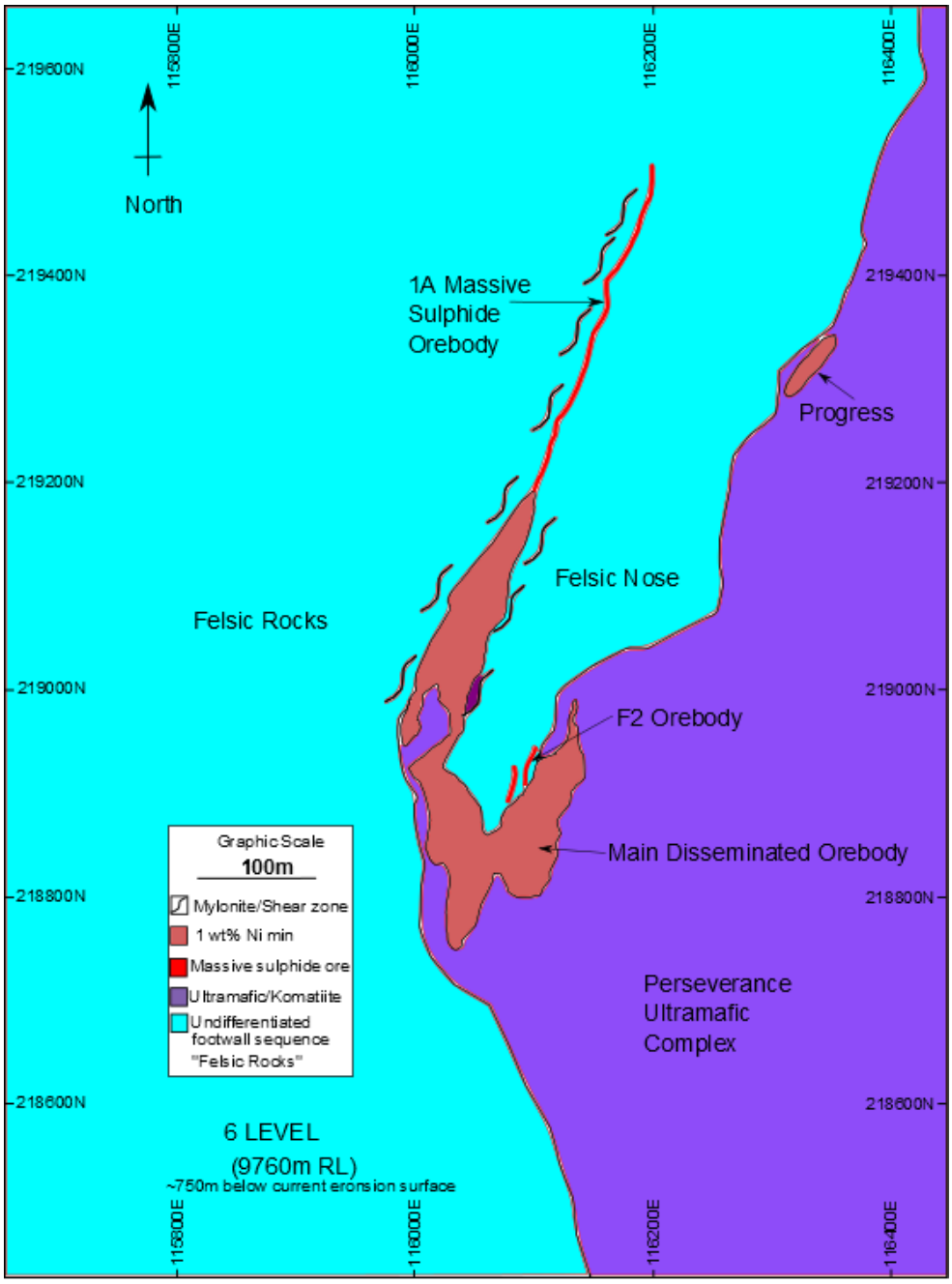


Figure 2.5. - Map showing the distribution of the Perseverance nickel sulphide deposits (from Journeaux, 2009). Coordinates (in meters) and North is on local mine grid (rotated 19º 35' 46" West of True North and 20º40' 00" West of MGA Zone 50 Grid North).

2.2.3 Structural Geology

Seven deformation events with a wide range of significance and styles have been identified at the Perseverance deposit (Journeaux, 2009 and Duuring at al, 2004). However, due to several superimposed regional folding and faulting events, it is difficult to distinguish all of the events and their chronological sequence. The

following is a summary of the deformation history at Perseverance, based on Journeaux, 2009 and Duuring et al 2004 and 2010:

Table 2.1. - Deformation events at Perseverance deposit summarised in the context of the regional deformation events (from Duuring et al, 2010).

Regional Deformation events (D)	Deformation events at Perseverance deposit (DP)
Pre-D1	Footwall volcanic pile formation?: dacitic-rhyodacitic porphyritic volcanic rocks (after 2711 Ma) - Perseverance ultramafic complex - Hanging wall sedimentary rocks and komatiite units.
D1	DP1 to DP3 : N-S shortening causing thrust imbrication of stratigraphy - 1A, Hanging wall Limb and Felsic Nose non-cylindrical, F3 folds duplicate the Perseverance stratigraphy - L2 stretching lineation to NW - Penetrative syn-metamorphic deformation culminating in composite S1,2 tectonic layering (ca. 2633-2634 Ma) - mylonite along footwall contact - Massive sulphides remobilized into 0.5-5 m wide, massive sulphide stringers sub parallel to the axial plane of F3 folds
D2	DP4: ESE-WNW shortening causing regional upright folds: - Abundant, asymmetric, NNW-striking, shallowly to moderately N-plunging F4 folds - S4 biotite and muscovite fabric - L4 crenulation/intersection lineation (10°-45° to NNW) - W-side down shear sense on shear zones
	DP5: Vertical shortening forms open recumbent folding of steeply dipping stratigraphy and fabrics - Late cross-cutting pegmatites
D3	DP6: WSW-ENE shortening: - N- to NE-striking, steeply W-dipping, dextral shear zones - East-west striking, sub vertical, extension veins and dolerite dyke
D4 and Post D4	DP7: ESE-WNW shortening: - Sinistral movement on the NNW-striking Perseverance Fault - Shallowly, SE-dipping faults cut the dolerite dyke with minor, apparent W-side down, displacements

2.2.4 Metamorphism and alteration of ultramafic rocks

The Perseverance Ultramafic Complex locally shows well-preserved igneous cumulate textures that are locally defined by magmatic olivine but are more commonly pseudomorphed by metamorphic olivine and serpentine. The dunite lens is concentrically zoned in terms of metamorphic mineral assemblages due to variations in local metamorphic fluid/rock mass ratios combined with the effects of magmatic crystal differentiation (Gole et al, 1987; Archibald and Power, 1997). Gole et al (1987) estimated the temperature of the prograde peak metamorphic event to be 535°C to 560°C (±50ºC) based on garnet-biotite geothermometry. Maximum pressures are considered to be around 3 kbar, based on an assumed maximum temperature of 550°C. Peak metamorphic conditions are interpreted to have reached mid-amphibolite grade and metamorphic mineral reactions are

thought by most workers to be isochemical except for moderate addition of H_2O and CO_2 in the ultramafic complex. The intensity of alteration as well as the rarity of primary textures preserved along the edges of the ultramafic body (primary textures are preserved in only some parts of the deposit, mostly in the core of the ultramafic complex), has made it difficult to definitively define the protolith of the local country rock types. Archibald and Power (1997) and Tait (1999) have suggested possible enrichments in Mg, Ca and Al in the ultramafic rocks during metamorphism. Gole et al (1987) defined a gradational alteration contact, which can be divided into chlorite-tremolite ultramafic rocks in the footwall contact; followed by olivine-anthophyllite, and then olivine-talc zones with occasional olivine-antigorite zones towards the central part of the Ultramafic Complex. These rocks have been classified as the product of prograde alteration resulting from peak metamorphism. The olivine is largely relict with preserved cumulate textures in the main central part of the dunite complex, which is the section of the ultramafic complex least affected by alteration, while recrystallised neoblastic and granoblasticts olivines are common along the western contact (Gole et al, 1987). Retrograde alteration has resulted in serpentinisation of the basal portion of the ultramafic complex, especially in the zone above the main inflection of the felsic nose. Here, lizardite is the main serpentine mineral with minor antigorite. Texturally, the lizardite can be fine to coarse grained, often granoblastic or pseudomorphing olivine, with fine to coarse bladed textures common in areas of greater strain (Journeaux, 2009). Distinct bands of talc-carbonate alteration are also present throughout the serpentinised zone (which are not clearly part of pre or post peak metamorphism). These bands are more common closer to the hangingwall contact and around deformed zones in the serpentinised ultramafic rock. This talc-carbonate alteration typically has a ‘spotted’ appearance, partially overprinting the lizardite with rarer thin zones of massive carbonate alteration (Gole et al, 1987).

Thicker zones of massive carbonates are common in the 9540 to 9465 production levels. A typical mineral assemblage for the carbonate zones is talc-magnesite-amphibole (tremolite, cummingtonite and/or anthophyllite)-chlorite, with rare calcite granoblasts. At lower levels of the mine, especially below the 9670 level the diffuse serpentinisation front gradually retreats toward the western footwall contact with increasing depth. Below the 9415 level, the serpentinisation front is present only as a thin serpentinisation layer, generally about 20 m thick, and a 6-10m wide

'transitional' zone of mixed serpentine/olivine (based on XRD assays, Appendix 2 and Chapter 3).

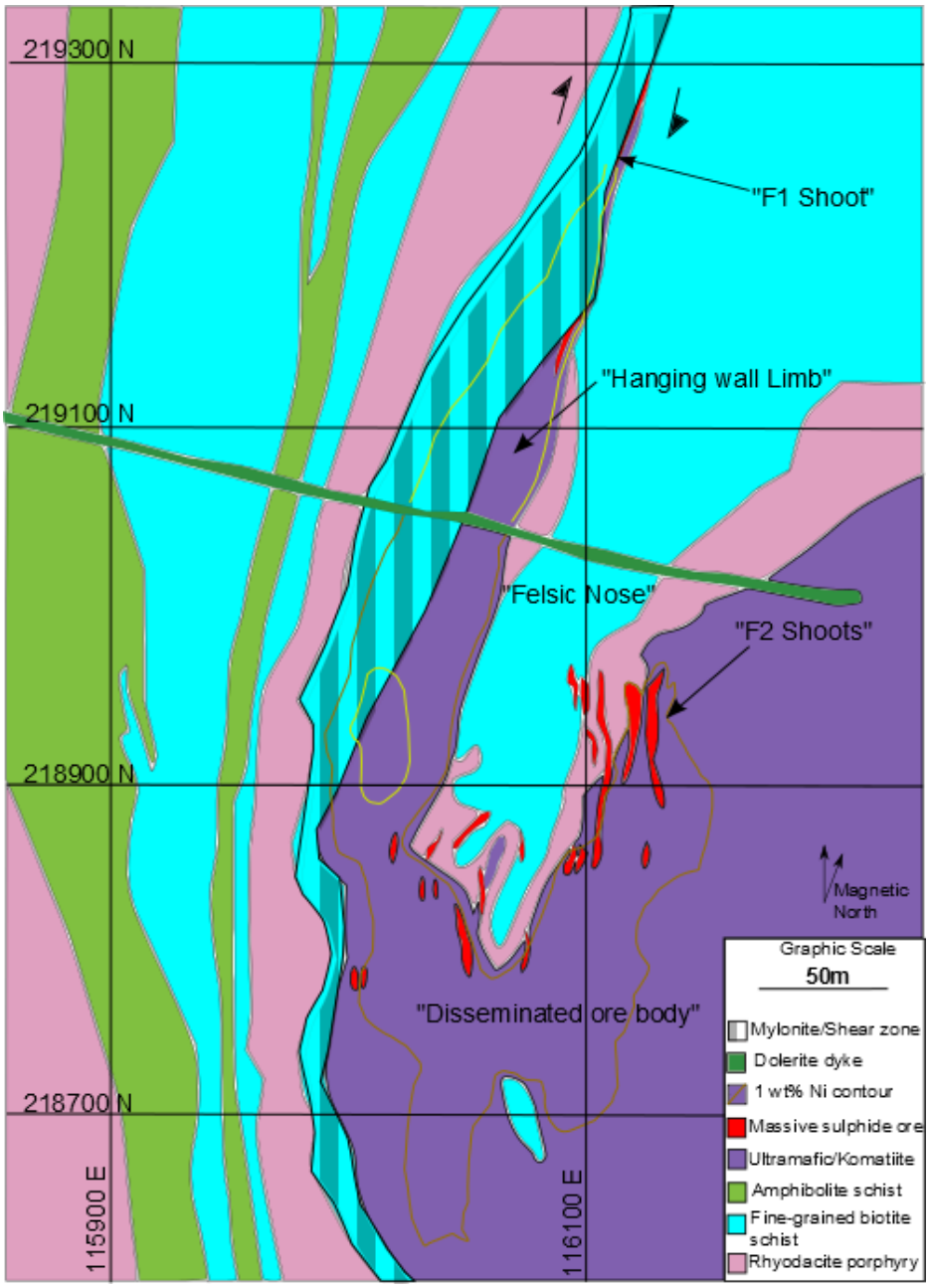


Figure 2.6. - Simplified geological plan view from the mine level RL 9760m (750 m below surface) based on drilling and underground mapping that shows the distribution of rock types, nickel sulphide ore bodies, and major structures and fabrics at Perseverance. Note the mine terminology for geographical locations in the deposit, including the Felsic Nose, Hanging wall limb, 1A massive sulphide shoot (F1 shoot), F2 massive sulphide shoots, and disseminated ore body positions (modified from Duuring et al, 2004). Coordinates shown are in mine local grid and North is on local mine grid (rotated 19º 35' 46" West of True North and 20º40' 00" West of MGA Zone 50 Grid North) and footwall sequence classified with all individual members.

3. MACROSCOPIC DISTRIBUTION OF ARSENIC AT THE PERSEVERANCE DEPOSIT

3.1. High arsenic domain definition and macro distribution

Elevated arsenic concentrations within the Perseverance orebody have long been known in the upper levels, from the natural surface to approximately 700m below it, in northern parts of the deposit in the areas of the 1A and F2 massive sulphide ore shoots and along the footwall massive sulphide rocks. As the mine was developed, new information was obtained on the distribution of arsenic-rich zones. New observations in the deposit, documented in this study, have revealed inclusion of high arsenic areas in the disseminated and matrix sulphide ore along the basal portion of the PUC. The ultramafic rocks are generally altered and are positioned between the sheared contact zone on the footwall and the western limb of the felsic nose.

The high arsenic domain in the study area was defined as a volume of rock with As geochemistry higher than 50 ppm of As in content of in-situ rock, regardless its geological boundaries (PUC or footwall sequence). This domain was constructed based on drillholes located between approximately 760 m to 1,400 below present surface erosion and limited by local X coordinates of 116,000 to 116,250 m and Y 218,700 to 219,500 m (based on local mine grid, which is rotated 19º 35’ 46” West of True North and 20º40’ 00” West of MGA Zone 50 Grid North). A total of 1,128 completed diamond holes with a total length of 229,203 m, with 61,694 individual assayed samples covering 82,332 m were selected for the arsenic distribution map. The remaining 146,871 m are in waste rocks which were not sampled as per company’s procedure. Only Fe, Ni, Co, MgO, Cu, Cr, As and S assays and rock lithology codes were made available from the whole company’s database for publication. Samples for ultramafic rocks were taken between 2 m to 4 m into the mining hangingwall past mineralised contacts. Maximum sample lengths are 2 m with a minimum sample length of 0.1 m in mineralised zones and commonly 1 m sample for massive sulphide intervals (sample intervals were determined by visual evidence of any sulphide in rock). Samples did not include logged geological boundaries. Figure 3.1 shows the histogram of sample lengths selected.

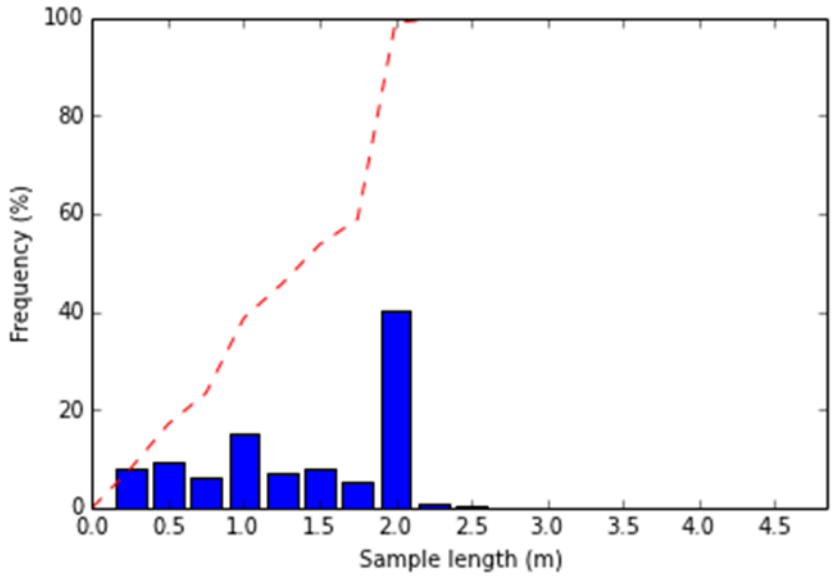


Figure 3.1. - Histogram of sample length (m) and number of samples per bin of all drill holes available of the study area

All 61,694 individual samples available in the company's database were assayed using inductively-coupled plasma optical emission spectroscopy (ICP-OES). Samples submitted between 1999 and 2003 have been assayed for LNO (Leister Nickel Operations) 'Suite 52' which comprises Ni, Cu, Co, Cr, As, Fe, Al, Mn, MgO and Zn. From 2003 onwards, 'Suite 60' has been used which comprises Ni, Cu, Co, Cr, As, Fe, Al, MgO and S (more details in Appendix 1). The laboratory assay procedure is detailed in the LNO QAQC Protocols and Procedures (Appendix 1). Returned assays were entered into the geological database by the site database administrator. The company's site geologist responsible for the hole validates the geochemical results against the logging. Any discrepancies or gaps are highlighted and the interval either re-logged or re-assayed at the laboratory from the pulp or another sample of quarter core taken and sent for check assays. Once resolved the results are signed off by the geologist. Arsenic assays are completed by pressed pellet and XRF with a detection limit of 5 ppm and samples which were below detection limit were assigned values of 2.5 ppm.

Using the selected drillholes and domain classification described above, a 3D "wireframe" model was created in Datamine Software to better evaluate spatially the distribution of arsenic in the selected part of the deposit (located between approximately 760m to 1,400 m below present surface erosion). The 50 ppm As metallurgical cut-off was used to split the high and low arsenic domains. The 3D wireframe was built based on digital vertical WE sections (total of 30 sections), which were spaced every 25 m along the Y axis (25m is the spacing between

underground production drives which also controlled the drill spacing). The sections were later “linked” into a digital solid wireframe, which was later used for spatial and statistical analyses (for sample selection and geometric evaluation). Due to the erratic distribution of As and some modelling constrains, a small number of samples comprising 1 or 2 intervals (varying from 0.1 m to a maximum of 4 m) of high arsenic were located inside some of the low arsenic domains and vice-versa. This modelling technique is similar to the procedure utilised to build the Ni 1% shell, according to the company’s protocol, which also contains small number of samples with less than 1% Ni within the shell and is an example of the current practice for resource estimation of high arsenic areas. Figure 3.2 A, shows a typical WE section and selected intervals for the high arsenic domain. Samples were then allocated to the high and low arsenic domains (Figure 3.2) utilizing the As wireframe for sample selection.

The high As domain contains 5,901 samples and shows two indistinct populations with peaks at 100 and 5,000 ppm As (Figure 3.3A). Analysis of the geometry of the high arsenic domain indicates high arsenic concentrations located within the massive sulphide orebodies (1A and F2 massive sulphide orebodies) and within disseminated sulphides in ultramafic rocks between 9590 RL to 9415 RL, with extremely high values in massive sulphide in the footwall contact between 9565RL to 9465 RL (Figures 3.4, 3.6 and 3.7).

The low As domain contains 55,793 samples, and has a strongly skewed population with approximately 83% of the samples sitting between 2.5 to 20 ppm arsenic, and a long tail with small number of samples with values above 50 ppm (Fig. 3.3B). A total of approximately 96% of the total samples range from 2.5 to 50 ppm As. Some samples above 50 ppm As were included into the low As domain due to the limitations of the modelling technique used for sectional interpretation, and erratic distribution of As.

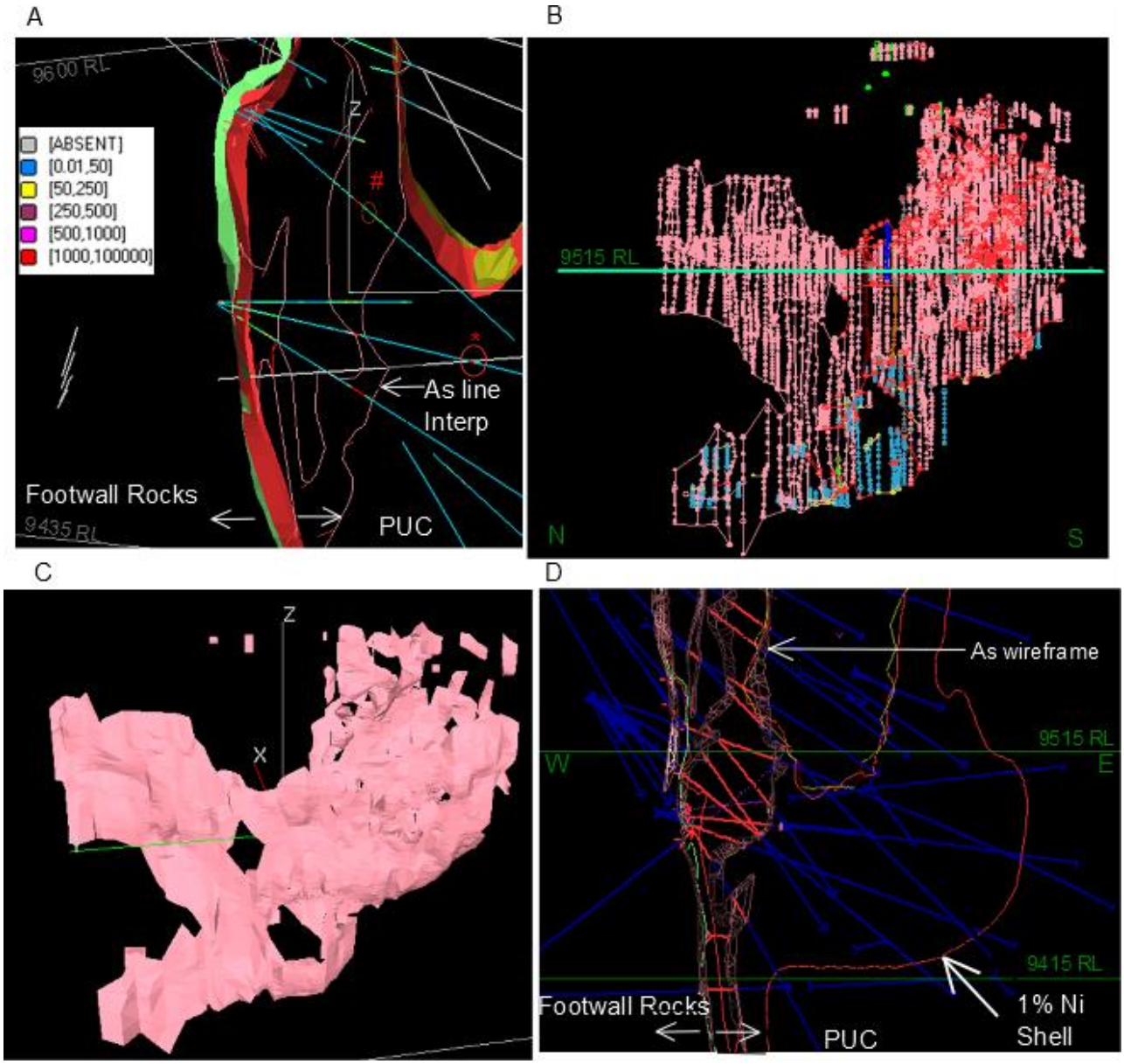


Figure 3.2. - Schematic sequence for arsenic wireframe modelling and sample selection inside and outside high arsenic domain. (***A)*** **–** perspective view of WE section 218875 m (local grid) with 25 m view clipping showing diamond drill holes coloured by As content of the whole rock (legend on image), PUC contact and digital line interpretation which contours most of the high As assays. Note values of high As (*) with no spatial correlation, which was left outside the wireframe and low As (#) inside wireframe, vertical view section from mine levels 9600 RL to 9435 RL represents 165 m (***B)*** **–** perspective NS view of all As digital lines spaced approximately 25 m apart (Legend on Figure A). (***C)*** **–** perspective NS of the As solid wireframe based on the digital lines. (***D)*** **–** WE section 218900 (local grid) with 25 m view clipping showing diamond drill holes coloured by samples inside (red traces) and outside (blue traces) As solid wireframe, PUC contact and 1 %Ni shell are shown. North is on mine grid, which is rotated 19º 35’ 46” West of True North and 20º40’ 00” West of MGA Zone 50 Grid North.

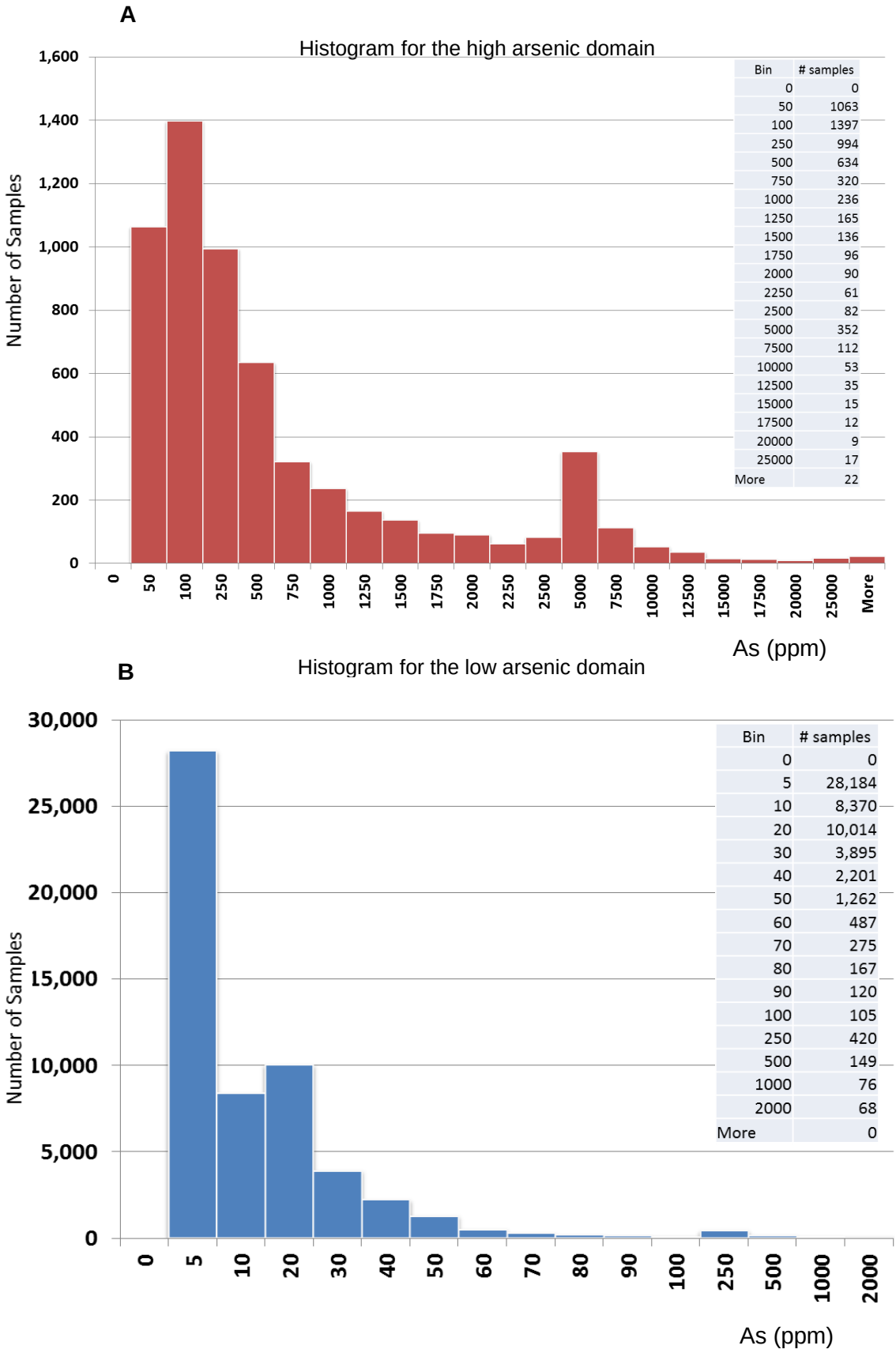


Figure 3.3. - Histograms of As contents for the high (A) and the low (B) arsenic domains. Note the small mixed populations around 2,000ppm for the high arsenic domain and the data distribution of a very strong positive skewed population for the low arsenic domain.

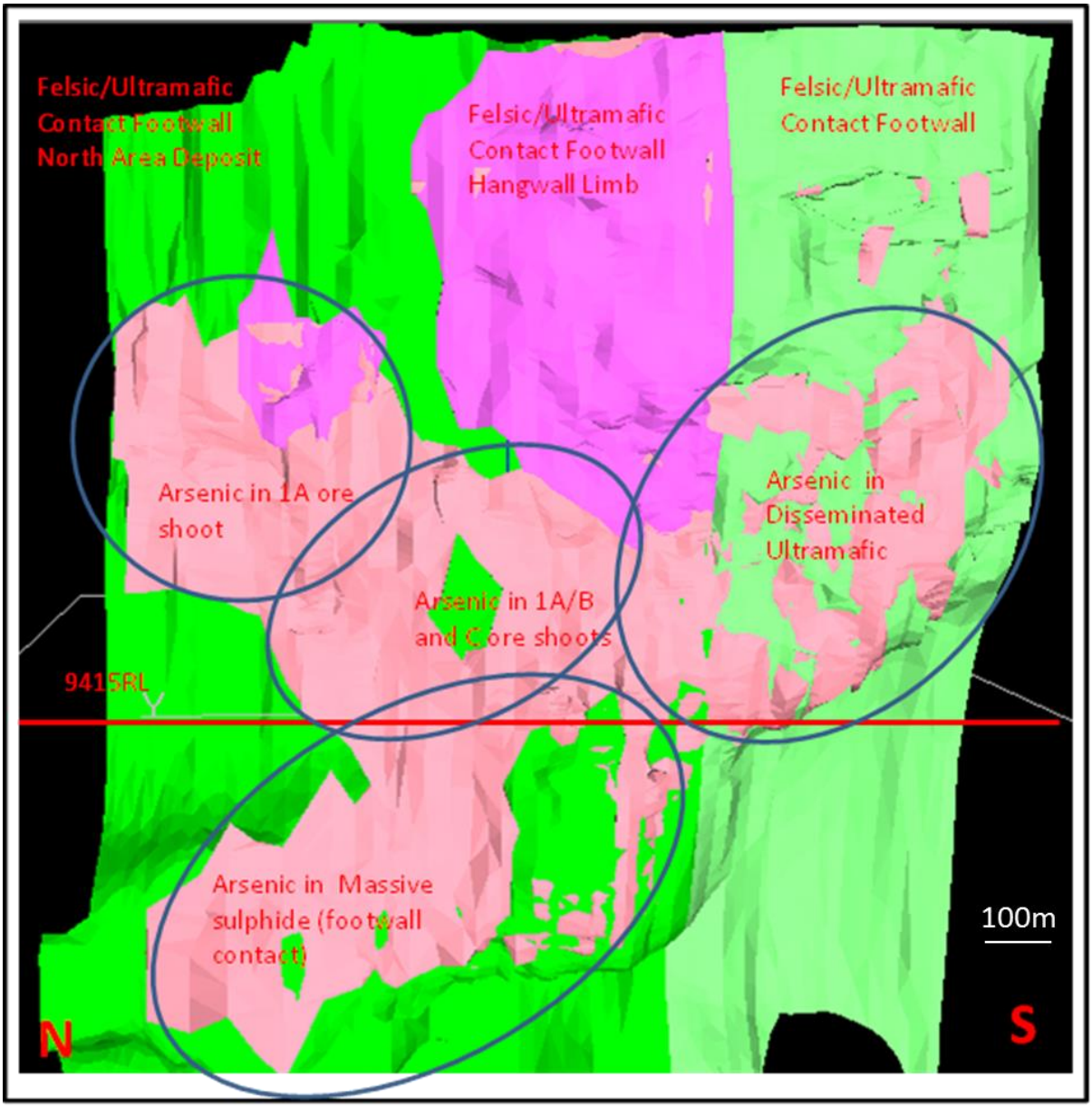


Figure 3.4. - North/South perspective view looking east shows ultramafic/felsic footwall contact (light green (southern domain), darker green (northern domain) and purple on the mining “hang wall limb”). Pink zones are the high arsenic domain with cut-off of 50ppm. The main arsenic zones are; 1A (upper most northern area); 1A /B/C (central area); disseminated and massive sulphide along felsic contacts (south area) and predominantly along massive sulphides in the contact zone (lower north and central zone). Red line shows the 9415 RL level. North is on mine grid, which is rotated 19º 35’ 46” West of True North and 20º40’ 00” West of MGA Zone 50 Grid North with graphic scale shown on figure.

When comparing the envelope of the arsenic-rich zones from the 3D model with the geological data, it is possible to see an overlap of the arsenic-rich zones with NS to N/NE striking foliation/shear zones that dip 70º–90º to the W and with a slight plunge to N particular below 9565RL to 9415RL. The arsenic-rich zone also overlaps with massive sulphide pods on the basal contact, with minor remobilized massive sulphide veins extending into the footwall rocks (Figure 3.6 – Plan view of

9490RL, Figure 3.7 – vertical West/East section on the Perseverance Ultramafic Complex and the Footwall Rocks). The serpentinite and massive sulphide-rich areas are located in basal parts of the PUC, (Chapter 2 – Geology of the Perseverance Deposit), which coincides with areas with higher amounts of shear zones and the presence of intense alteration (serpentinisation and carbonation of the ultramafic rocks). Due to the high mobility of arsenic, its concentration contours follow the boundaries of major altered zones and there are no significant structures that offset the continuity of the arsenic distribution and its major association. The geometry and distribution of As are therefore consistent with mobilisation of As by a relatively late event.

Local	Ni (wt%)	As (ppm)	Calcite (%)	Chlorite (%)	Dolomite (%)	Pent (%)	Gersd (%)	Pyrr (%)	Serp (%)	Tre (%)
Vein	0.6	100	49	0	12	3	0	16	0	18
Wall	3.44	4055	3	4	9	18	6	39	17	4

Figure 3.5. - Photo of a development drive, with high arsenic concentration in altered ultramafic rocks in contact with carbonate vein (9515 level – drive xc31 - PUC). The blue circle shows carbonate veins (dolomite and calcite) with massive sulphides (presence of coarse secondary pentlandite) and sulpharsenide. Mineral proportions based on XRD analyses. Pen (pentlandite), Gersd (gersdorffite), Pyrr (pyrrhotite), Serp (serpentine) and Tre (tremolite).

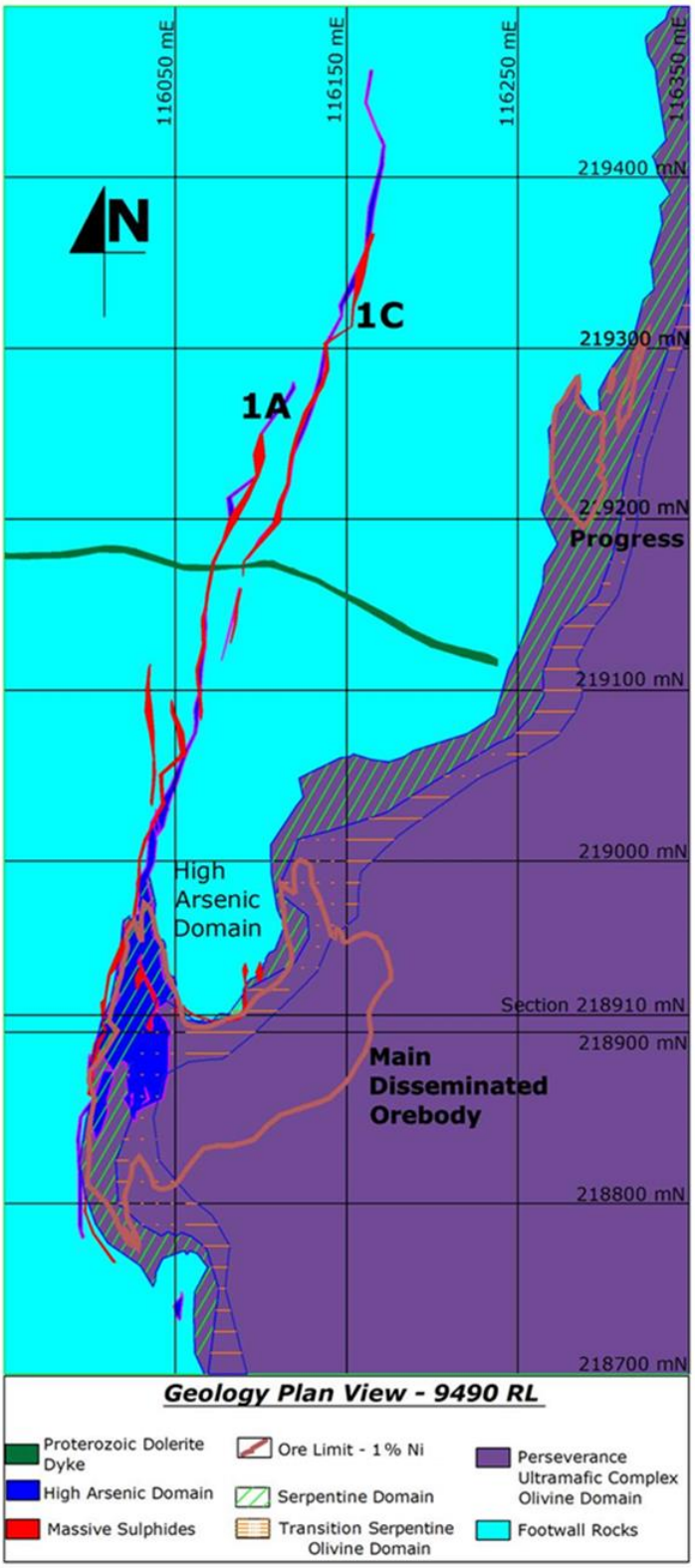


Figure 3.6. - Geological plan view of 9490RL that shows the distribution of rock types, nickel sulphide ore bodies (Main Disseminated Orebody and Progress are examples of matrix and heavily disseminated sulphide ore), and major structures and fabrics at Perseverance and the relationship of the high arsenic domain (shell limits from slice of the As wireframe) against the main geology features (data from the resource model from June 2010 by the author). North is on the mine grid, which is rotated 19º 35’ 46” West of True North and 20º40’ 00” West of MGA Zone 50 Grid North.

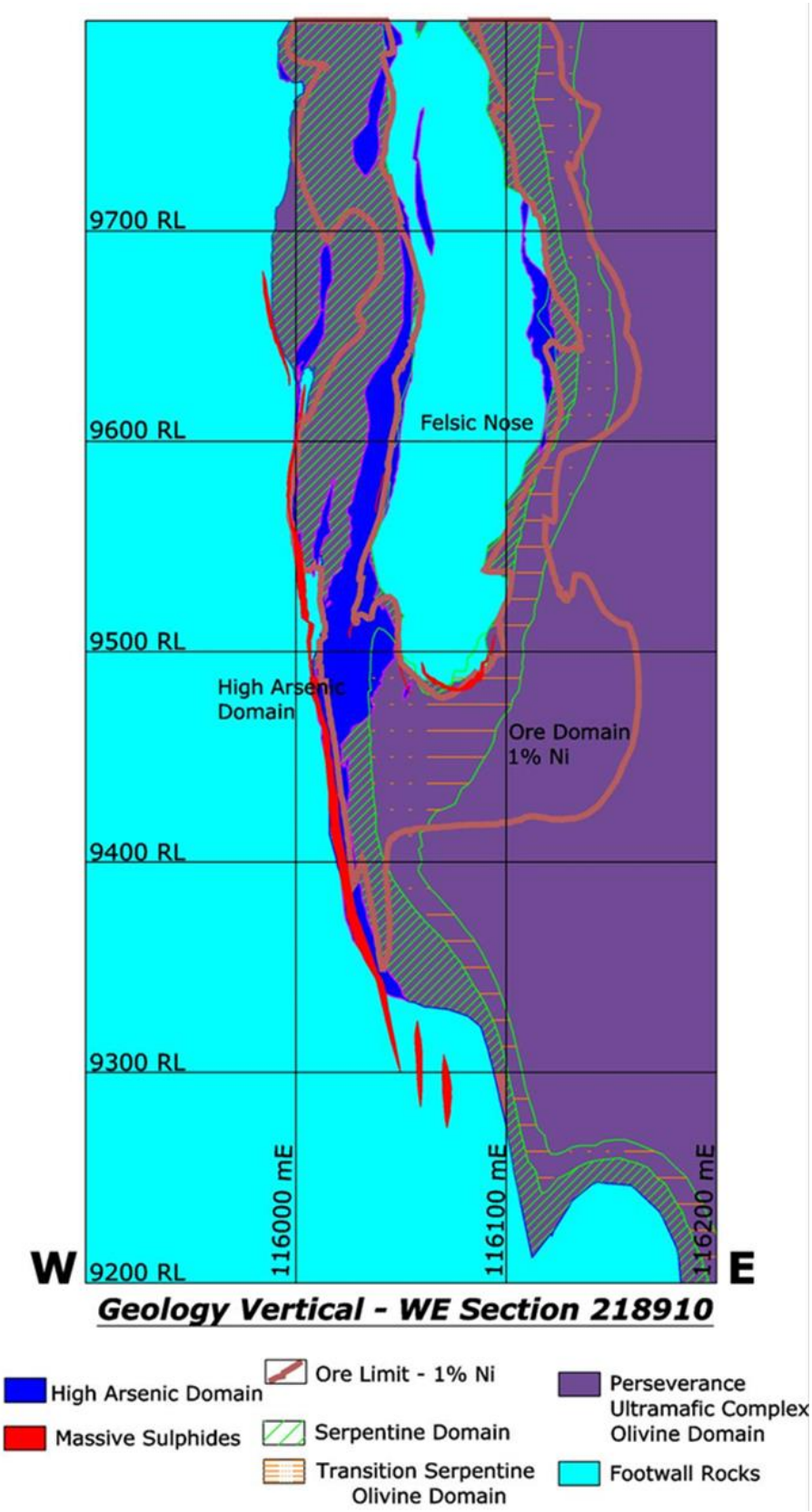


Figure 3.7. - Geological West-East vertical section on local 218910 N 9490RL showing the relationship of the high arsenic domain (shell limits from slice the of As wireframe) against the main geology features (data from the resource model from June 2010 2010 by the author). North is on the mine grid, which is rotated 19º 35' 46" West of True North and 20º40' 00" West of MGA Zone 50 Grid North. The Ore Domain 1% Ni contour shown outlines the matrix and heavily disseminated sulphide Main Orebody.

3.2. Correlation of arsenic and other common chalcophile elements in the high arsenic domain

A statistical analysis of relationships between common chalcophile elements was conducted for the high As domain on 5,670 individual samples from the total 5,901. The remainder were omitted due to a lack of assays in some elements, mostly Cu, Co and some Fe (Table 3.1 illustrates the general statistics). Element correlations of As against Co, Cu, Ni and Fe for the high arsenic domain were calculated based on scatter plots, which are shown on Figures 3.8 and 3.9. Based on the data distribution Cu, Ni and Fe do not show any significant correlation with As. The As-Fe and As-Ni plots (Figure 3.8 A and B respectively) contain two distinct populations, located at approximately Fe above 30% wt and Ni above 5.5% wt, but those represent the samples from matrix and disseminated ore (below Fe of 35% and Ni below 5.5%), while the other population is represented by samples of massive sulphide. Cobalt is the only one of the elements investigated that has any suggestion of a correlation with arsenic, with As/Co having a correlation coefficient of 0.20 and level of significance (p value) of 0.0527 for all 5,670 samples, and a correlation coefficient of 0.745 and level of significance of 3.8E-61 for samples above 1,000 ppm As (total of 1,184 samples). For comparison, other correlation coefficients for the 5,670 samples are: As/Fe of 0.066, As/Ni of 0.094 and As/Cu of 0.097. The significant correlation between As and Co can be explained by the presence of small amounts of cobalt in all sulpharsenides present in the study area (Figure 3.9 B); this hypothesis is supported by the data from the microanalyses described in Chapter 6.

Table 3.1 – General statistics of As, Co, Cu, Fe, Ni and sample length of all samples contained inside the high As domain.

General Statistics	As (ppm)	Co (ppm)	Cu (ppm)	Fe (%)	Ni (%)	Length (m)
Number of samples	5,670	5,670	5,670	5,670	5,670	5,670
Minimum	2.5	2.5	2.5	0.1	0.1	0.1
Maximum	97,000.0	40,500.0	22,800.0	61.3	11.5	2.90
Mean	1,069.20	898.2	1,394.00	22.5	3.1	0.90
Median	149	536	1,000.00	18.2	2.2	0.80
Standard Deviation	3,298.80	1,865.90	1,564.50	15.5	2.6	0.61
Interquartile Range	679	1,158.30	1,365.00	25.6	4.4	1.00
Range	96,997.5	40,497.5	22,799.0	61.3	11.5	2.9
25 percentile	61	213	435	9.8	0.9	0.35
75 percentile	740	1,371.30	1,800.00	35.4	5.3	1.35
99 percentile	15,034.7	3,314.5	7,607.8	54.6	9.1	2

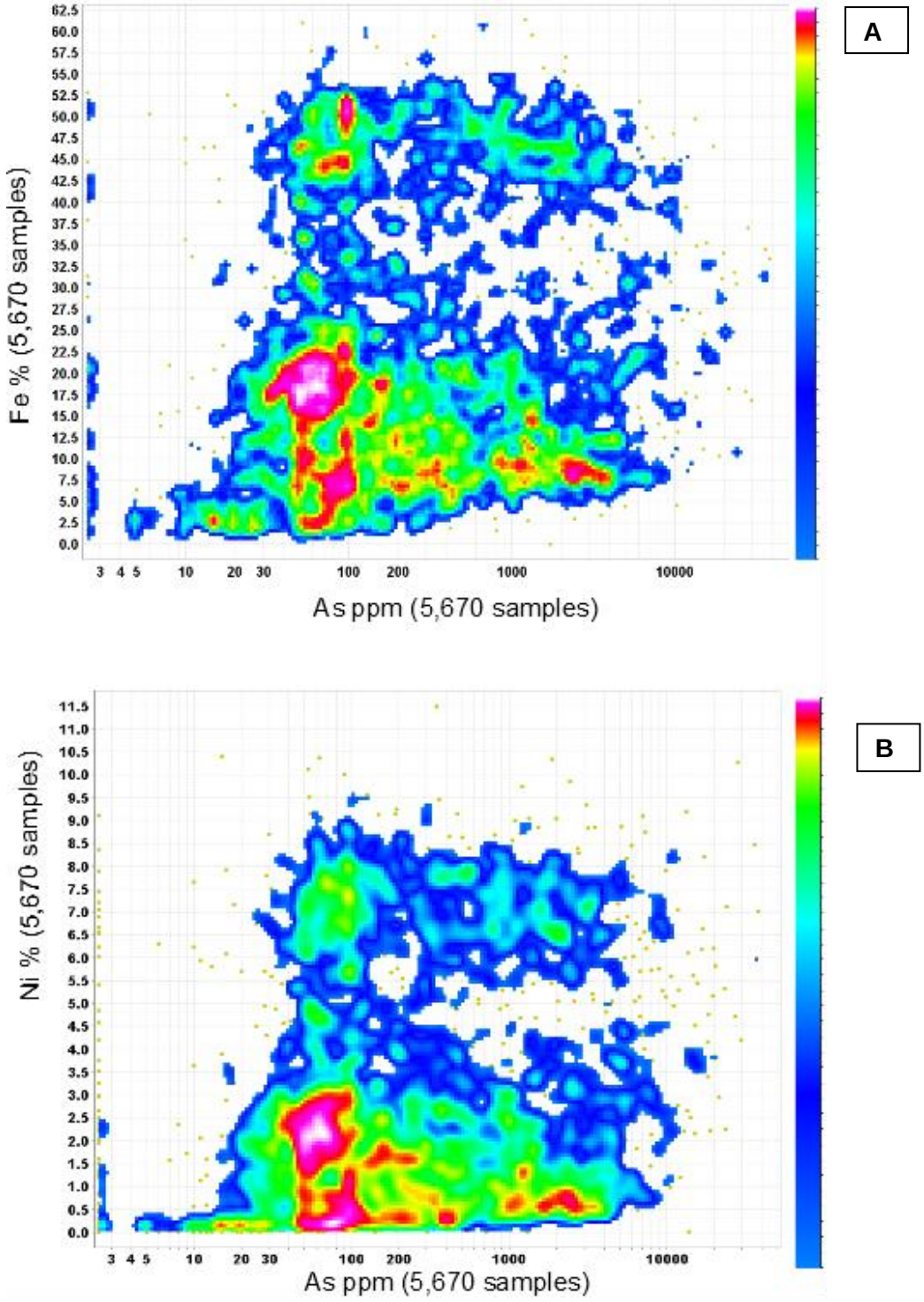


Figure 3.8. - Scatter plots of As-Fe (A) and As-Ni (B) for high arsenic domain samples. Ni and Fe are plotted on a linear scale and As is on a logarithmic scale. The contour map shown is based on samples which are overlapping or in close proximity with a 0.1 cell size used for map and bar scale based on 1 to 2 samples per cell. Individual points with no overlaps are shown by the green dots. Note that not all high arsenic areas are located in the massive sulphide rocks, as shown by the 2 populations in the graph (division at approximately Fe above 30% wt and Ni above 4.5% wt).

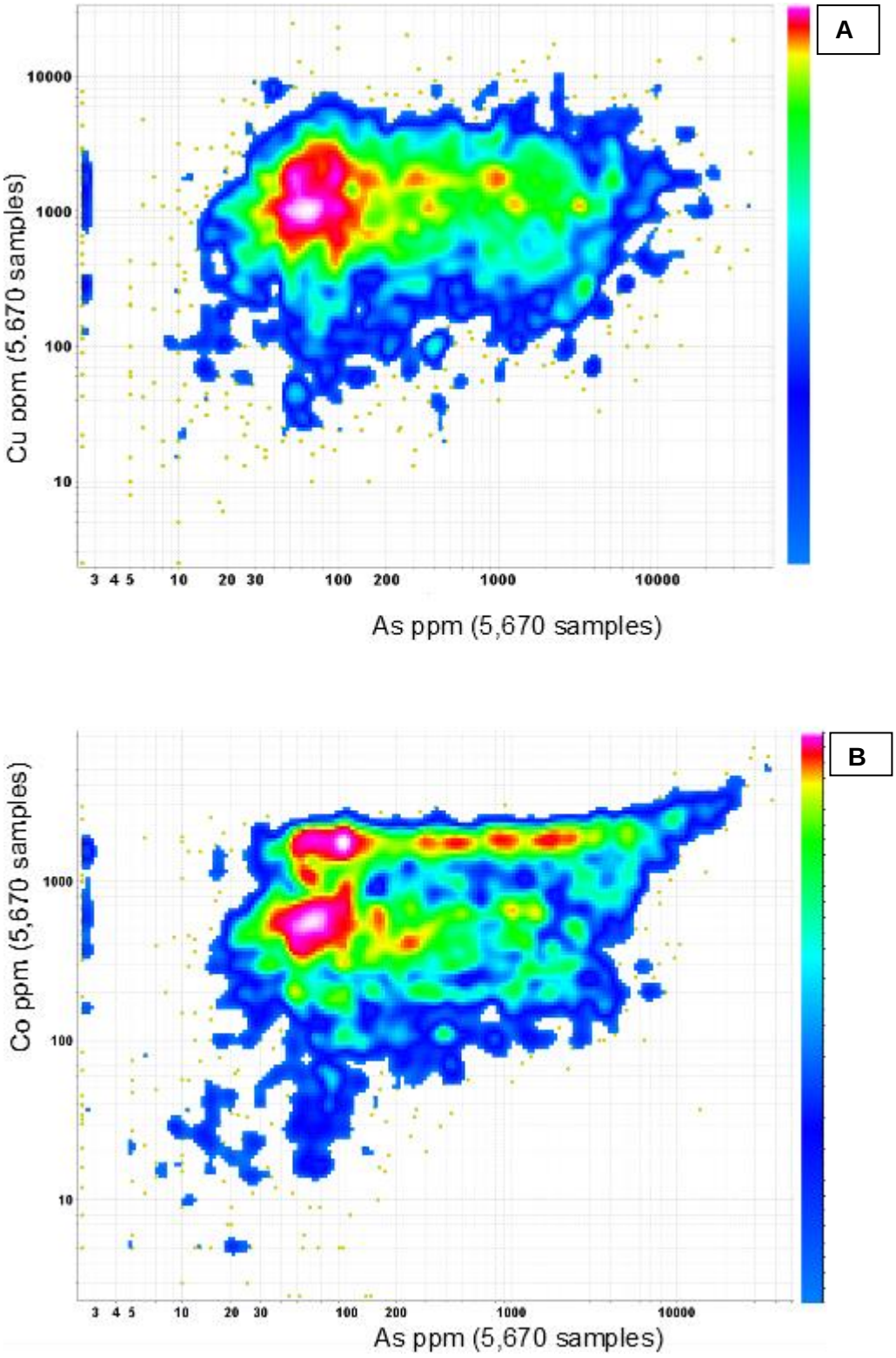


Figure 3.9. - Scatter plots of As-Cu (A) and As-Co (B) for high arsenic domain samples. Note that the only small correlation shown in the scatters is As-Co, though the correlation is sub-significant at the 95% level. Cu, Co and As are plotted on a logarithmic scale. The contour map is based on samples which are overlapping or in close proximity with a 0.1 cell size used for map and bar scale based on 1 to 3 samples per cell. Individual points with no overlaps are shown by the green dots.

3.3. Summary of macro distribution of the high arsenic domain

- In summary, there is one main macro zone associated with high concentrations of arsenic, which is located along the base of the PUC and inside the serpentine and transition domains. The high arsenic zone is approximately 700 to 800 m long with a N/NE strike (local mine grid) and 600 m dip direction following almost a 90º angle. This zone is focussed on areas that are intensely sheared, such as the small massive sulphide pods that occur at the contact of Perseverance Ultramafic Complex and Footwall rocks), and along massive sulphide shoots like 1A, 1B, 1C and F2. These zones are located mainly in the serpentine-rich domain of the PUC and can also host carbonates (dolomite and calcite) and recrystallised sulphides plus sulpharsenides. Arsenic-rich areas occur from the basal contact of PUC to a maximum of 40 m towards the upper parts of the orebody. There are some minor high arsenic zones that occur a little further inside the PUC, especially between 9565RL and 9415RL. These zones are located in an area inside the transition zone between serpentine and olivine domains, mostly around the “felsic nose”, however the areas richest in arsenic in that area are located inside the transition zone between serpentine and olivine domains, and are also connected to the main As-rich zone along the faults (Figures 3.6 and 3.7).
- Although the spatial modelling of the high As zone has some limitations, especially with respect to sample selection and the erratic distribution of arsenic, it can be a useful tool to determine the distribution of arsenic concentrations within the deposit. The construction of models like that described here will support estimation processes like ordinary kriging, which is currently a company procedure.

4. SAMPLE SELECTION AND WHOLE ROCK DATA

This chapter provides descriptions of the samples selected from the study area, their spatial distribution within the deposit, and whole rock chemistry analyses. The results are discussed in the context of the characteristics of the high arsenic samples.

4.1. Sample criteria and spatial location

Samples for further analysis were taken from areas of anomalous arsenic concentrations in the mineralised and non-mineralised areas of the Perseverance Ultramafic Complex, particularly along the mining levels active during the period of this study, and close to the footwall contact (as the bulk of the mineralisation sits along the footwall contact of the Ultramafic Complex). The majority of samples used for this study were selected mainly from diamond core drilled from underground mining levels 9415 to 9515 (Figure 4.1) with in-situ locations of approximately 1,000 to 1,100m below present erosion surface. Most of the samples were taken from drill holes located at the levels 9490 (Figure 4.2) and 9515 (Figure 4.3). These two levels contain the highest concentration of arsenic within the deposit and were undergoing development whilst the samples were taken.

All samples were classified either as footwall or Perseverance Ultramafic Complex (with its sub domains). The PUC samples were sub-divided in four types, including massive sulphide and three ultramafic types, following the ultramafic alteration domains described in Chapter 2, section 2.2.4. The majority of the samples were selected from the base of the ultramafic complex, largely within the heavily disseminated mineralisation (net textured zone) and the altered serpentine-rich zone. The divisions of the ultramafic sample types were completed using three-dimensional surfaces. The surfaces were interpreted through the study area based on the XRD data by the site Mine Geology team, and they were produced using all the drill samples available at the company's database (the complete list of drillholes was not made available to be published for this study; only the wireframe was supplied for this work).

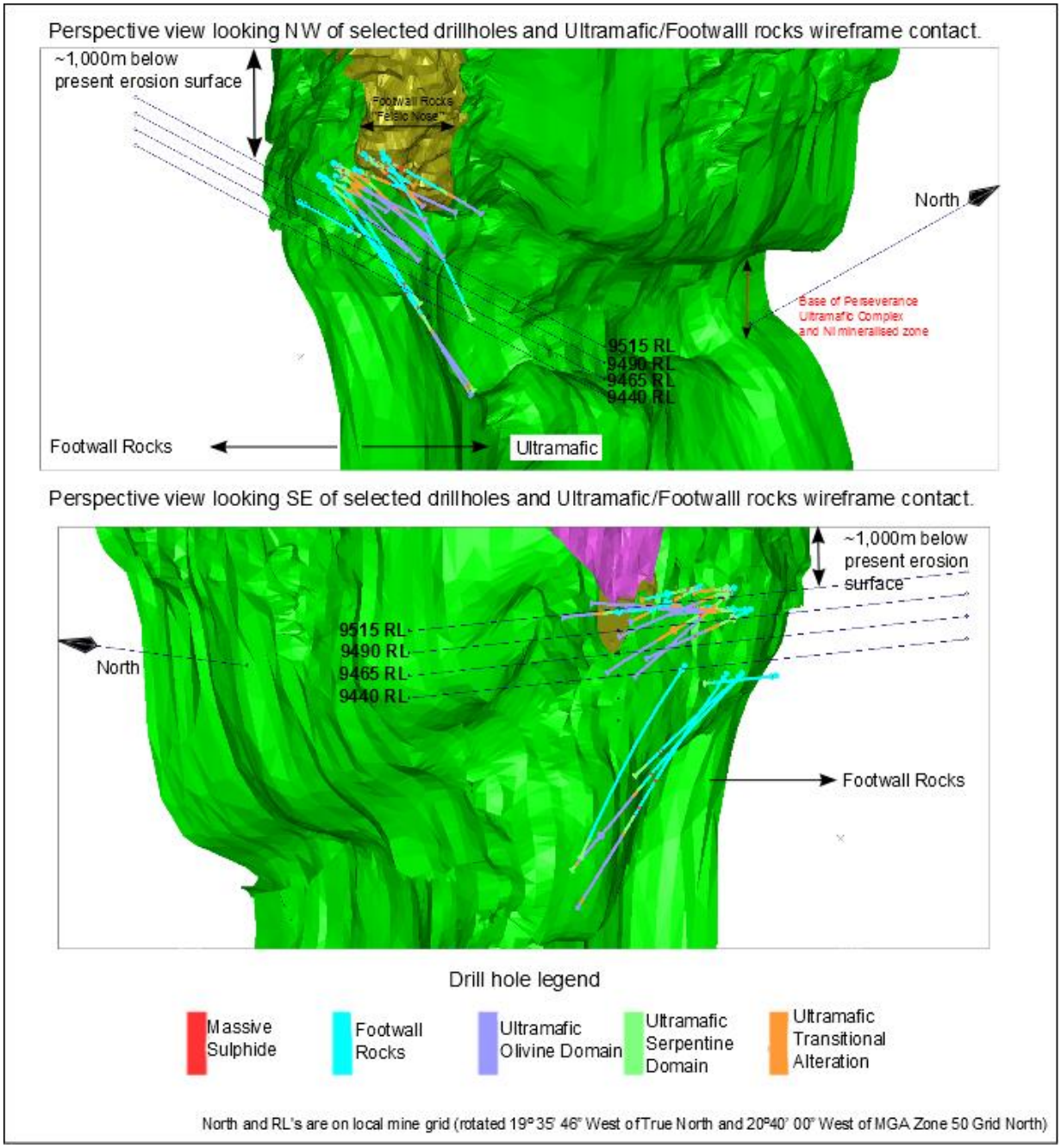


Figure 4.1. - Three-dimensional perspective views of the lower contact of Perseverance Ultramafic Complex (three-dimensional surface generated from BHP-Billiton mine model using Datamine Studio3 with light green area representing the main PUC basal contact, the pink area is located along the hangwall limb and the golden zone along the “felsic nose”) around the study area, Underground mine levels are 9515 to 9440 RL, three-dimensional projection of the selected diamond drillholes (coloured by rock type), predominantly selected from areas of matrix and massive (net-textured) ore. Projections are in the local mine grid.

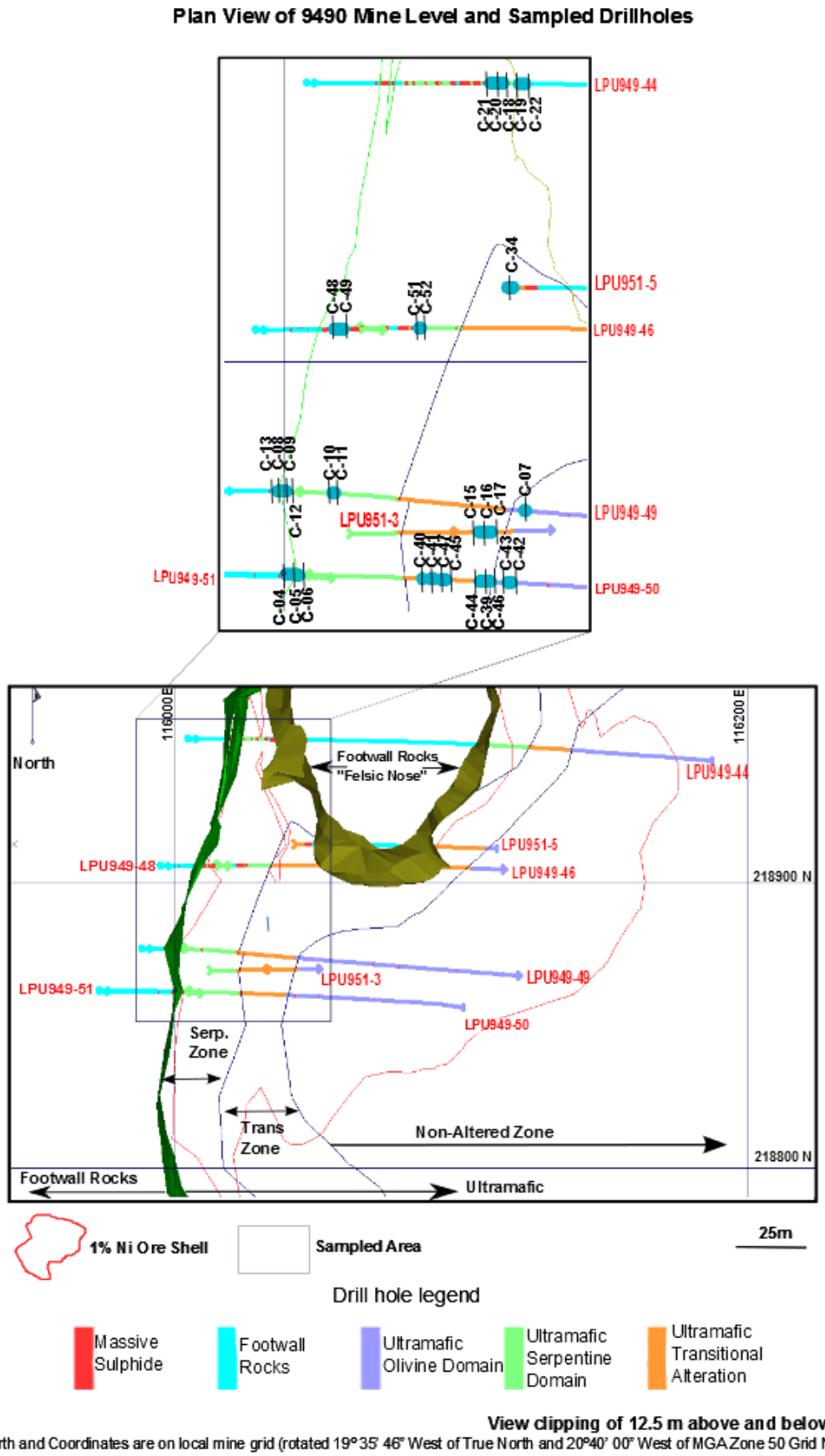


Figure 4.2. - Plan view of the 9490 level showing the base contact of the Perseverance Ultramafic Complex (surface projection between the Footwall Rocks and Ultramafic),projection of the selected diamond drillholes and samples, alteration zones and 1% Ni ore shell intersection on respective RL.

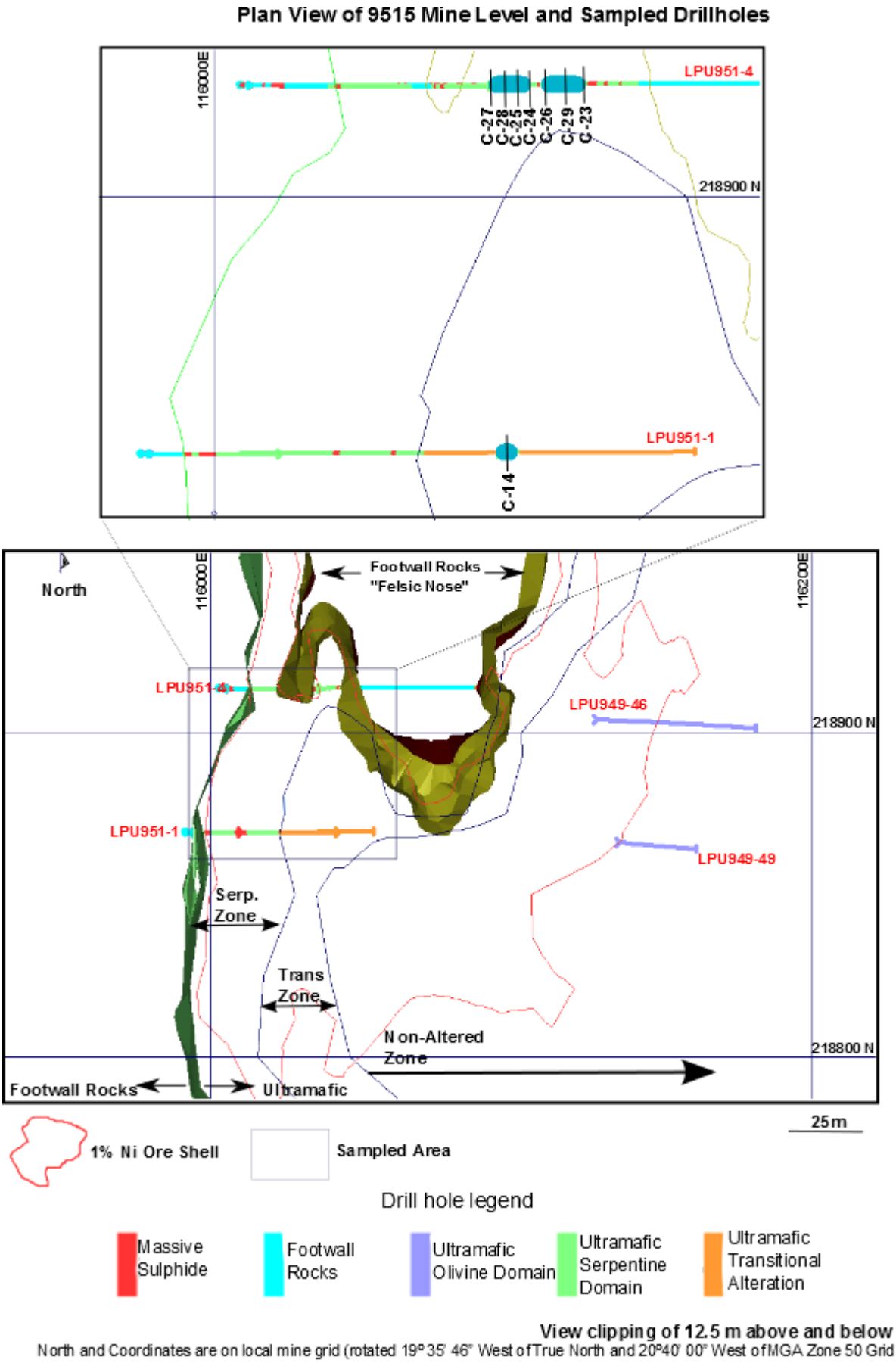


Figure 4.3. - Plan view of the 9515 level showing the base contact of the Perseverance Ultramafic Complex (surface projection between the Footwall Rocks and Ultramafic),projection of the selected diamond drillholes and zoom of samples, alteration zones and 1% Ni ore shell intersection on respective RL.

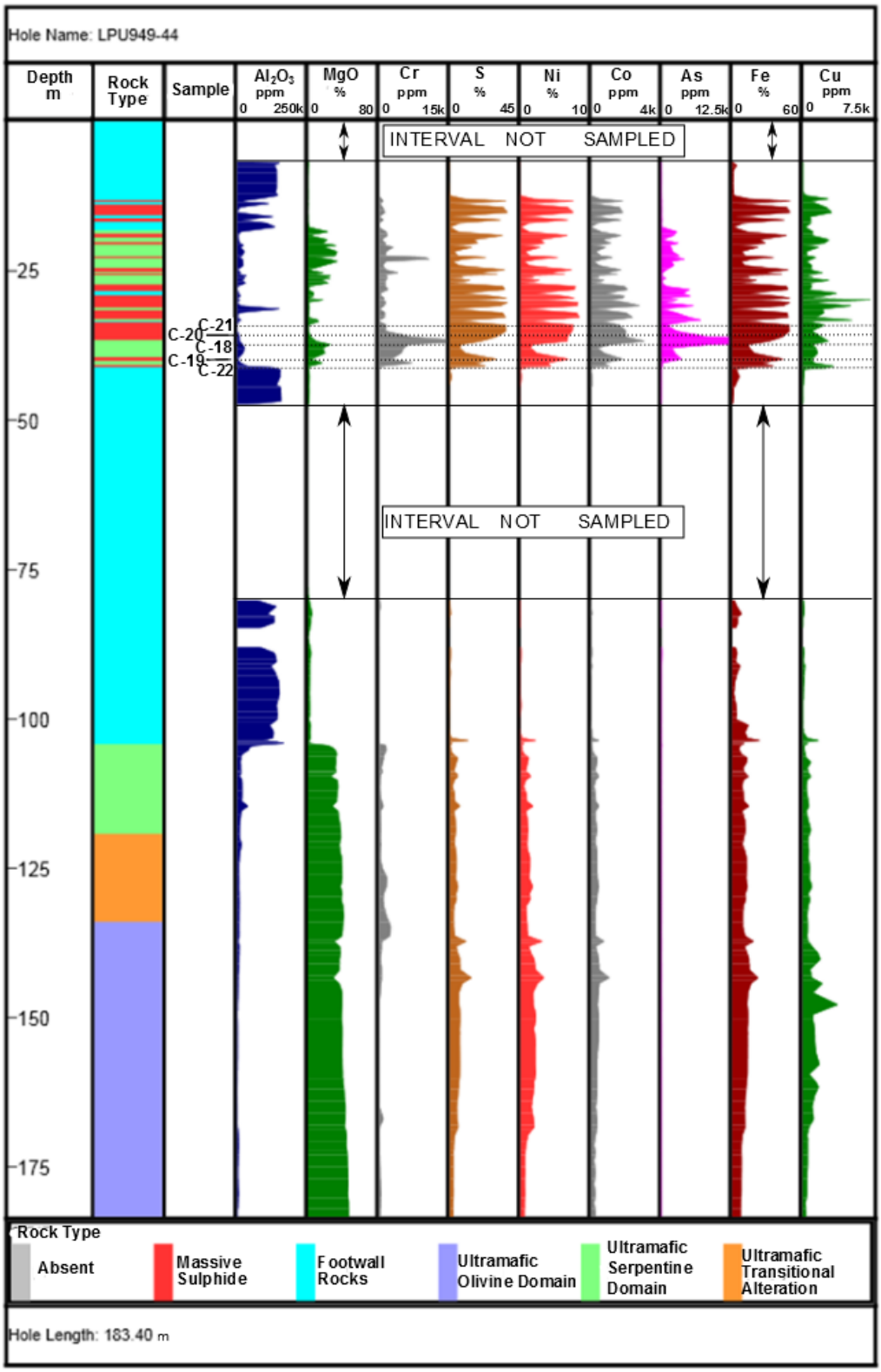


Figure 4.4. - LPU949-44 strip log of whole rock geochemistry, lithology, alteration and some of the selected samples for this study. Note the samples taken in the high arsenic intersection zones are along the basal contact with the felsic rocks and on massive sulphide intersections.

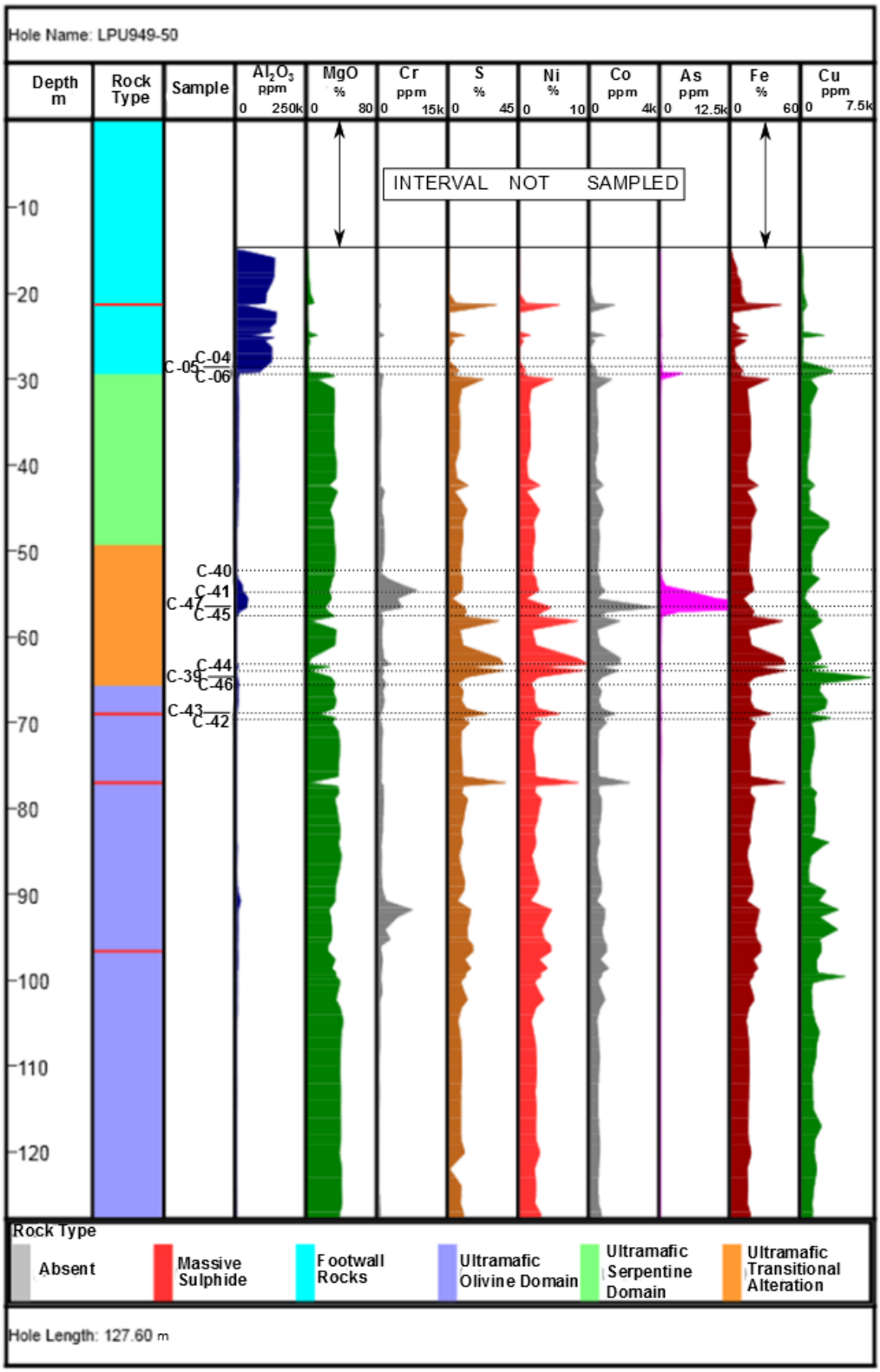


Figure 4.5. - LPU949-50 strip log of whole rock geochemistry, lithology, alteration and some of the selected samples for this study. Note the samples taken in the high arsenic intersection zones along the basal contact with the felsic rocks through the non-altered ultramafic sulphide disseminated zones with small sulphide veins.

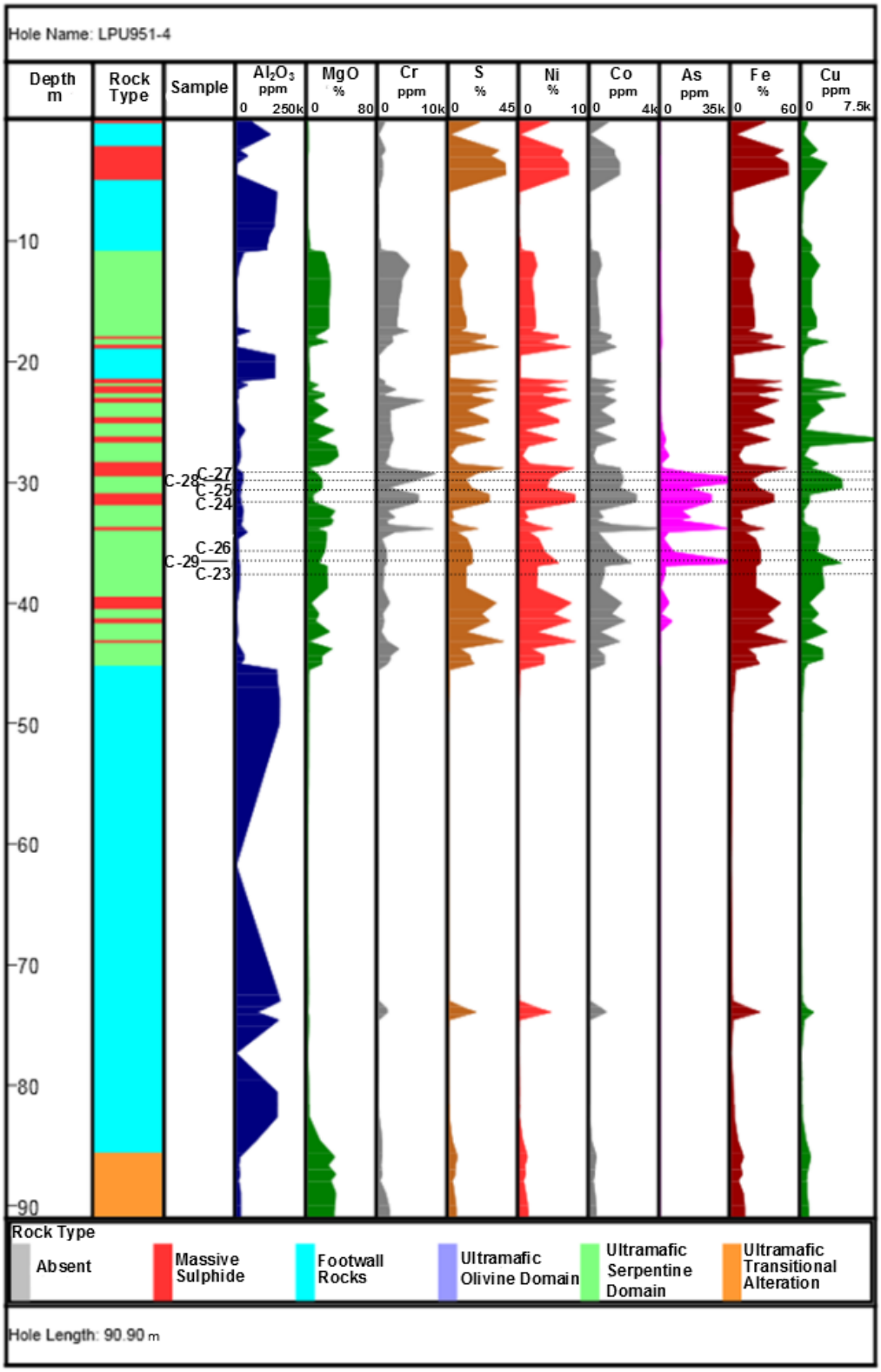


Figure 4.6.- LPU951-4 strip log of whole rock geochemistry, lithology, alteration and some of the selected samples for this study. Note the samples taken in the high arsenic intersection zones along the basal altered serpentine rich ultramafic rock with sulphide disseminated and massive sulphide microveins.

The general rule applied was that the serpentine domain contained less than 10 % olivine, and the olivine domain contained less than 10 % serpentine. The transitional domain contained greater than 10 % of both mineral species. This practice has also been used at the mine site to separate the alteration domains. The distribution of serpentine/olivine with a metamorphic bladed texture marks the limit of rocks affected by an original episode of serpentinisation, the bladed olivines having been generated by dehydration reactions during prograde metamorphism (Barnes et al, 2011). These olivine crystals have been subjected to a subsequent episode of post-metamorphic retrograde serpentinisation, which decreases in extent and intensity with depth below the present-day erosion surface. The retrograde serpentinisation is therefore thought to take place during weathering processes (Barnes et al, 2011).

4.2. Whole Rock Geochemistry of the Selected Drillholes from Footwall Rocks

The Footwall rocks from the selected drill holes are represented mainly by volcanic/sub volcanic and sedimentary units (Chapter 5 contains petrological description of the main units of the footwall rocks). Few samples were taken from the footwall rocks for petrological and SEM analyses (9 out of 64 total samples, not including samples from the contact with PUC), due to the weak association of these rocks with high arsenic values and high partial assay analyses for Ni. The footwall sequence does not contain high amounts of Ni mineralisation (close to zero in close proximity to the PUC contact), resulting in discontinuous sampling within the company's database, where few footwall rocks were generally assayed. The footwall rock samples with higher arsenic contents are mostly associated with veins of remobilized Ni-Fe massive sulphide from PUC, which were remobilized during metamorphic events. The massive sulphide veins and micro veins (veins with generally less than 5 cm in thickness) encountered at the footwall sequence are related to the 1A and F2 orebodies, but at small scales (less than 10 to 15 m long, which are not sufficiently continuous to be economically exploited). In some of the selected holes (Figures 4.4, 4.5 and 4.6 and also in Appendix 2, which contains all diamond drillhole striplog and geochemical data from selected holes), all Ni, As, Fe and S spikes in the footwall sequence are associated with Ni/Fe massive sulphide veins. In this case, analyses of whole rock from the Footwall sequence should be interpreted with caution; there is no evidence that associates Ni, As, Fe and S anomalies with the original Footwall sequence. Figure 4.7A

shows a Ni-S scatter plot of all assays from the selected drillholes within the Footwall rocks, while Figure 4.7B shows those Footwall rocks that do not contain remobilized Fe/Ni massive sulphide material; information was drawn from logging of massive sulphide veins and micro veins and a cut-off of Ni of 0.1 wt %. The plots in Figures 4.8 (scatter plots of Ni-As (A) and Ni-MgO (B) for footwall rock samples with no remobilized Ni-Fe massive sulphide from PUC) show the generally low arsenic contents of these samples, with all data around or below the 50 ppm As break value.

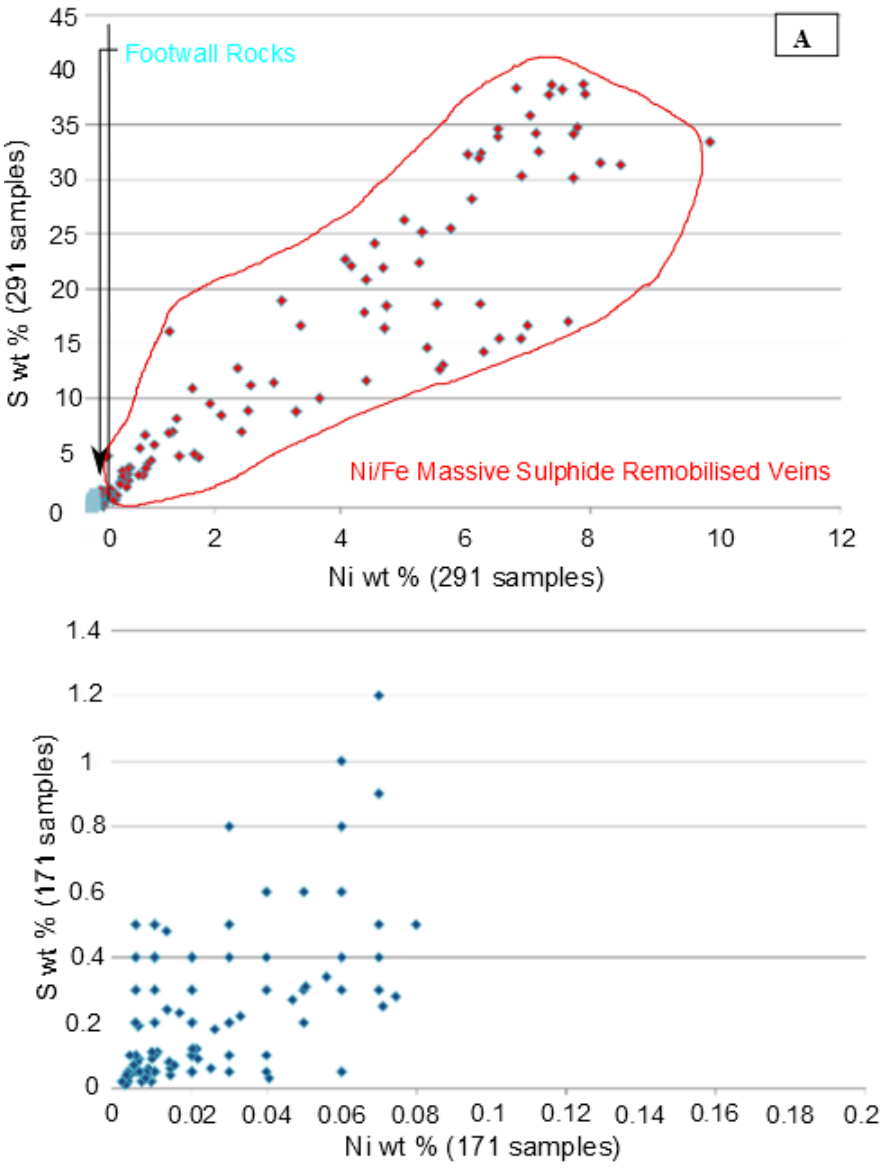


Figure 4.7. - Scatter plot of Ni-S (A) of all samples from Footwall rocks and remobilized massive sulphides veins or micro veins (blue dots represent footwall rocks and red represents remobilized massive sulphides). (B) is the scatter plot of Ni-S for footwall rock samples only. All axes are on linear scales. Samples are from the entire company's database.

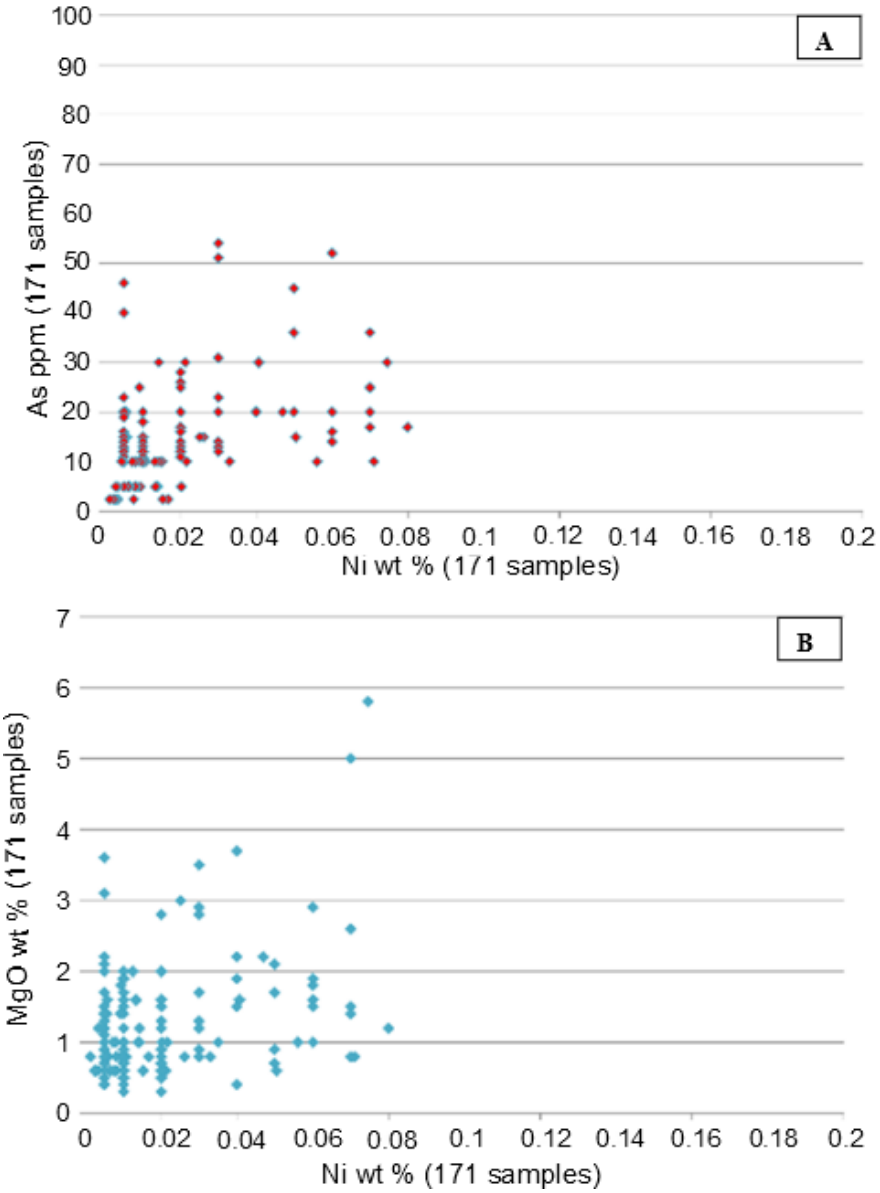


Figure 4.8. - Scatter plots of Ni-As (A) and Ni-MgO (B) for footwall rock samples with no remobilized Ni-Fe massive sulphide from PUC. All plots are in linear scale. Samples are from the entire company's database.

4.3. Whole Rock Geochemistry of the Selected Samples from PUC

The selected PUC rocks are represented mainly by matrix and disseminated sulphide ultramafic rocks and also by massive sulphides. The selected ultramafic rocks are examples of extremely pure olivine-sulphide cumulate and olivine-adcumulate with essentially no trapped komatiite liquid component and tremolite-chlorite-olivine rocks (also known as schists), corresponding to komatiite liquid and

olivine orthocumulate compositions with the tremolite-chlorite schists representing metakomatiites (modified original chilled margins or A zones of flows) and olivine-tremolite-chlorite schists corresponding to olivine orthocumulate (matching classification from Gole et al , 1987 and Barnes et al, 2011). All rocks have been overprinted by a series of later metamorphic/metasomatism alterations. The olivine-sulphide adcumulate examples contain bladed metamorphic olivine crystals that form elongate metamorphic olivine grains up to 5 cm in length within a continuous matrix of approximately 30 to 40% sulphide. Sulphides form typically a pyrrhotite, pentlandite, and chalcopyrite assemblage (Barnes et al, 2011). The olivine-sulphide adcumulate also include tremolite-chlorite-olivine schists, which are commonly present in the flanking rocks on either side of the ore lens, within a zone of protomylonite (Barnes et al, 2011 and 1988a). The samples selected from the ultramafic complex are generally from the extreme heavily disseminated matrix ore type, are sulphide rich and generally lie along the highly altered serpentine (lizardite) zone and mostly located along the western margin of the orebody. A selection of samples from the ultramafic rocks of the PUC (not including massive sulphides) were plotted on a MgO, CaO, Al_2O_3 ternary graph (Greshan and Loftus-Hill, 1981), Figure 4.9, with the sum of MgO, CaO, Al_2O_3 normalised to 100%.

The ternary plot on Figure 4.9 distinguishes adcumulate with levels of normalised MgO as high as 95%, through orthocumulate with 75 % to 95 % MgO, spinifex textured komatiites with 55 % to 75 % MgO and komatiitic basalts with 35% to 55% MgO. The theoretical fractionation paths for olivine and pyroxene in different zones within komatiite flows are also shown in Figure 4.9 (Hill et al, 1990). The plot of the selected samples confirms the adcumulate, olivine-orthocumulate and spinifex textured A-zones designation of the selected rocks following the classification of Barnes et al (2011), However, when analysing the data distribution on Figure 4.9 and also on Figure 4.10 (scatter plots of MgO/CaO (A) and MgO/Al_2O_3 (B)), it is noted that CaO contents of the rocks may not represent the original ultramafic composition, which may have been affected by metamorphic and metasomatic events. Metasomatic major element movement on some scale is consistent with the high amounts of carbonates in some of the samples (described on Chapter 5 and XRD analyses, located in Appendix 1), which results in a scattered and possibly unreliable plot (Figures 4.9 and 4.10A). CaO is generally considered an unreliable parameter for petrological classification because of the mobility of the Ca (Arndt et al, 2008).

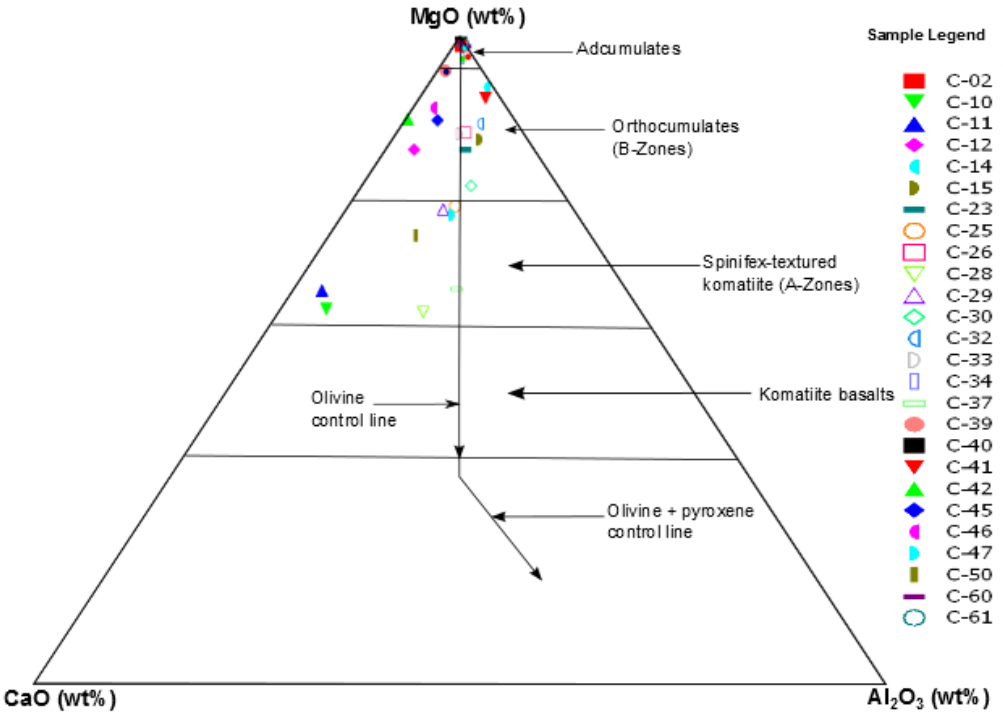


Figure 4.9. - MgO, CaO, Al_2O_3 plot of ultramafic samples of the study area (based on diagram from Greshan and Loftus-Hill, 1981). Major elements have been recalculated to 100% for plotting.

According to Arndt et al (2008) the petrologically most important element in komatiites is aluminium. The Al-content of unaltered komatiite rocks is controlled by high-degree mantle melting that leaves behind only olivine in the residue. Garnet is thought to occur in the residue of the majority of Al-depleted komatiites. Thus, komatiite Al contents globally tend to fall into one of two broadly similar compositional ranges, Al-depleted and Al-undepleted (Barnes et al, 2004). Variations of Al_2O_3/TiO_2 are one of the best ways for komatiite classification, because these elements are relatively immobile (Arndt et al, 2008). A preliminary attempt to discriminate the volcanic facies was made based on the Al/Ti content of the rocks. However the company's database did not contain TiO_2 assays for all samples, including the high arsenic samples selected for this study.

Additionally, a MgO to Al_2O_3 plot with theoretical mixing lines between pure olivine and equilibrium liquid for corresponding specified percent of trapped liquid (Barnes et al, 2011) could not be applied because most of the high arsenic samples contain high amounts of sulphide and sulpharsenides in areas of metasomatic alteration, which hinders effective comparison of samples.

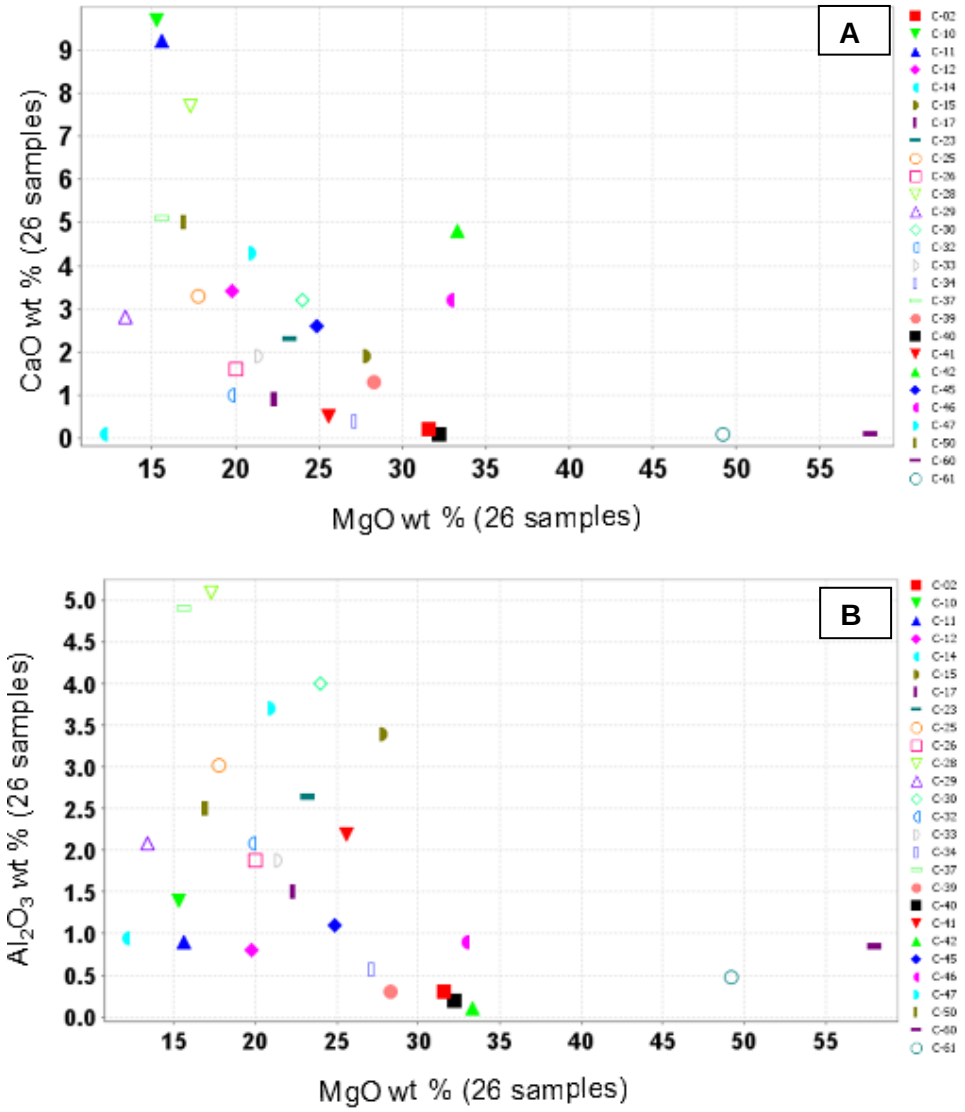


Figure 4.10. - Scatter plot of MgO-CaO (A) and scatter plot of MgO-Al_2O_3 (B) of PUC samples from the study area. Sample legend is shown on the bar, located on the right side.

A classification scheme was adopted based on the descriptions of Barnes et al (1988a) and Barnes et al (2011) to validate the plotted fields on Figure 4.9 and to confirm the classification of ultramafic rocks from the study area that did not fall inside the adcumulate zone (Figure 4.9). These rocks are sulphide-rich and are located along the basal portion of PUC, mostly in the main mineralisation zone. Barnes et al (1988a) and Barnes et al (2011) state that the PUC rocks that are olivine-sulphide cumulates are commonly rich in MgO and depleted in Al_2O_3, while the olivine-orthocumulate komatiite, mainly represented by tremolite-chlorite schists with some variations with olivine, is richer in Al_2O_3. Figure 4.11 shows the approach utilized to classify the ultramafic-sulphide rocks based on contents of MgO and Al_2O_3 normalized to SiO_2 to allow for the presence of sulphides (based on

classification of Barnes et al, 1988a). Chlorite and tremolite contents (based on XRD analyses) were also plotted on Figure 4.11 as a second validation tool for the division of samples into olivine-cumulate with matrix and disseminated sulphide (now mostly altered into sub products of metamorphism and metasomatism), olivine-orthocumulate komatiite and spinifex textured A-zones komatiite. The tremolite-chlorite-olivine rocks in the study area are located in a highly sheared zone (mylonitic zone, see Chapter 5) along the basal portion of the PUC.

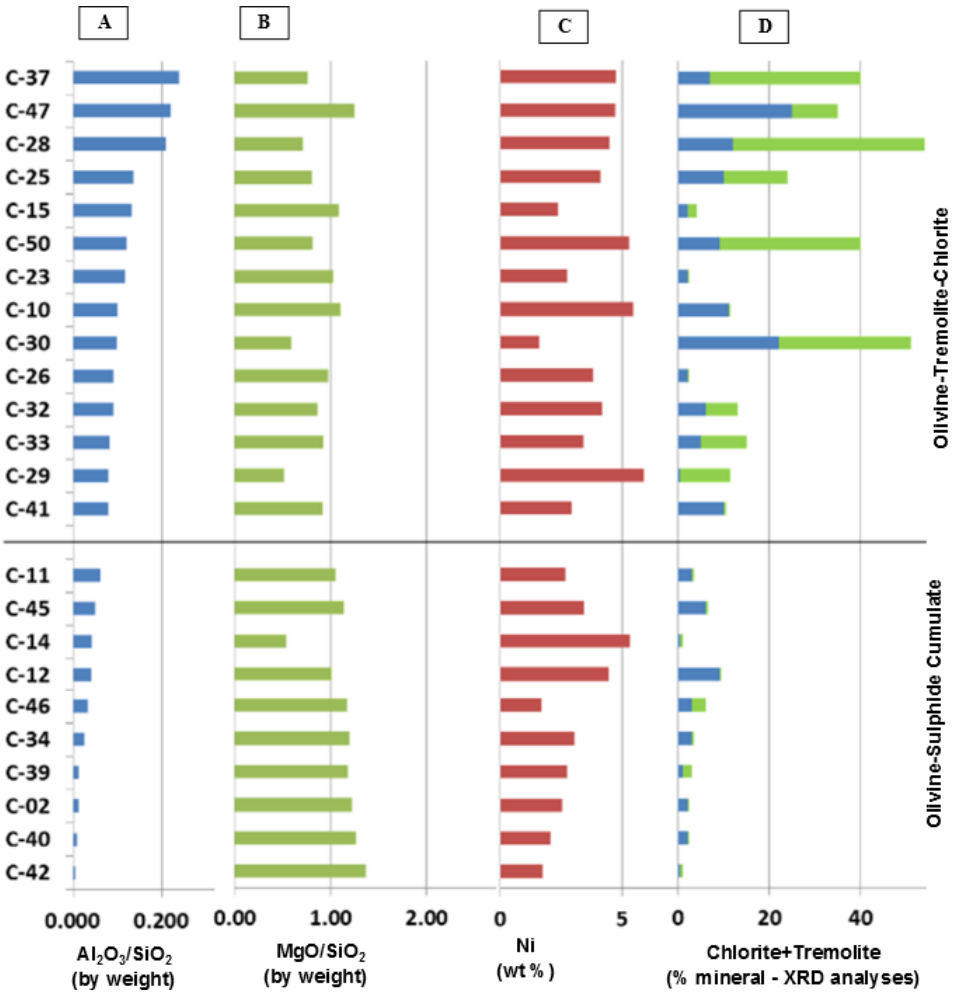


Figure 4.11. - Bar plots of Al_2O_3/SiO_2 (A), MgO/SiO_2 (B), Ni (C) and chlorite and tremolite content based on XRD analyses (D). MgO and Al_2O_3 normalized to SiO_2 to allow for the presence of sulphides (based on classification of Barnes et al, 1988a). Data includes rocks from PUC from the study area and does not include massive sulphide and adcumulate rock types. Classification utilized to separate samples from the study area from the PUC sequence into olivine-sulphide-orthocumulate + spinifex textured A-zones and olivine-sulphide cumulate.

At the Perseverance deposit, the majority of the rocks from the PUC are interpreted to have formed from chromite-under saturated magmas, although a small proportion of chromite-bearing samples are evident within the dunite lens (Barnes et al, 2011). A significant number of chromite-bearing samples occur in the study area, where intersections of elevated chromium, some with Cr in excess of 20,000 ppm can be found in the area (eg samples from drillholes LPU949-4, sample C-18, LPU949-50 and LPU951-4 located on Figures 4.4 and 4.6 & Appendix 1 & 2), particularly around the high arsenic zone. Some arsenic rich zones coincide with high chromium concentrations. High chromium concentrations in the PUC were also previous documented by Gole et al (1987) who found that chrome spinel was a common accessory in the tremolite-chlorite-bearing rocks and its formation (Cr-spinel) was attributed to re-equilibration of relict igneous chromite with the metamorphic silicate assemblage (Gole et al, 1987). However chromite is not present within all high arsenic zones as most of the high arsenic rich areas are not anomalous in chromium concentrations (Figure 4.12). Further details of the relationship between whole rock data, mineral proportions and nickel tenor for the selected samples from PUC are discussed in Chapters 5 and 6.

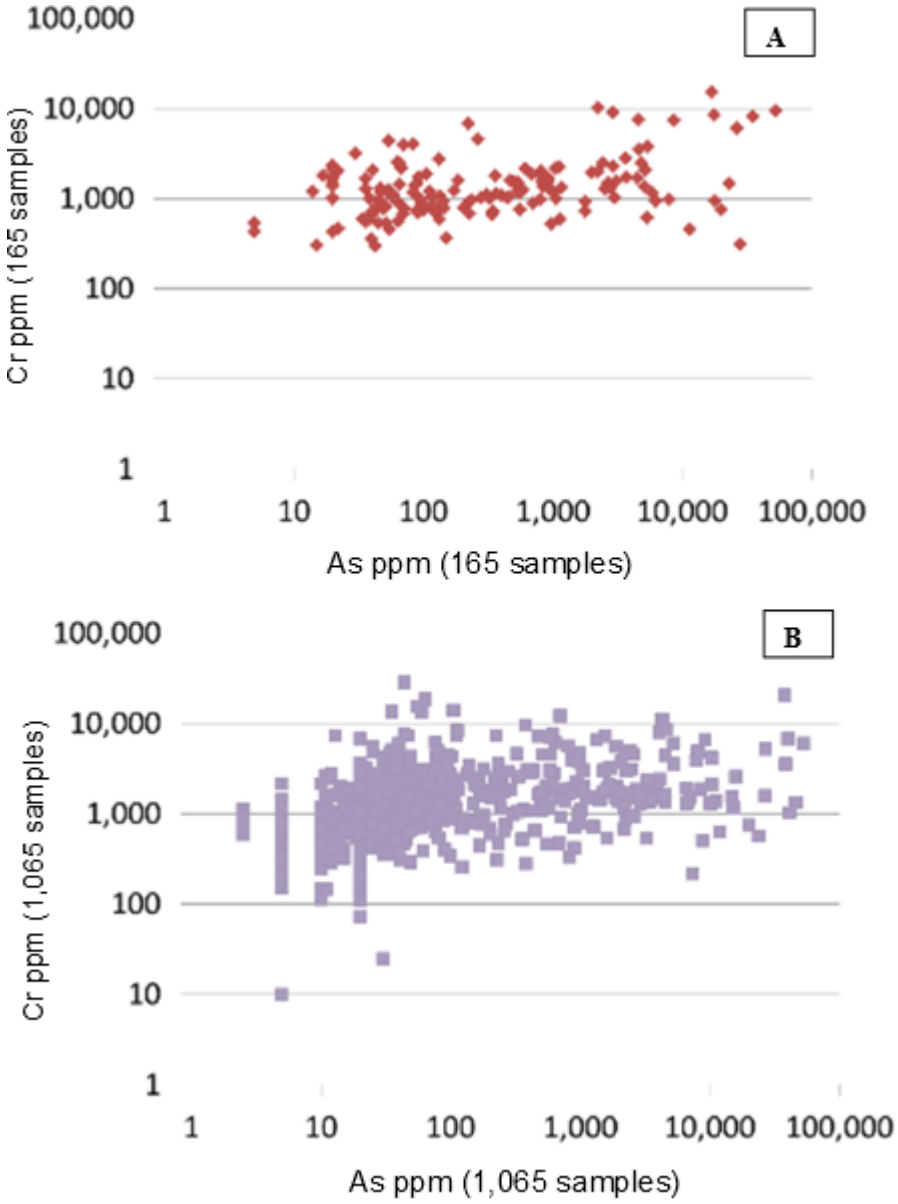


Figure 4.12. - Scatter plot of As-Cr for the selected drill holes from massive sulphide rock types (A) and scatter plot of As-Cr for the selected drill holes from ultramafic matrix and disseminated sulphide rock types (B). As and Cr are plotted on a logarithmic scale. Note groups of As concentrations values at 2.5, 5 10 and 20, which represent the detection limits and half of detection limit of samples assayed before and after 2003 (Suite 52 and 60 respectively, described in Chapter 3).

4.4. Summary of whole rock geochemistry

The following summarises the results of sample selection and whole rock geochemistry:

- The majority of the samples were selected from areas of anomalously high arsenic, which tends to concentrate at the base of the ultramafic complex (PUC), located at the underground mining levels 9415 to 9515 (approximately 1,000 below present erosion surface).
- The high As samples are mainly found within the matrix and heavily disseminated mineralisation that includes the net textured zone with disseminated and matrix ore, and massive sulphide veins that are within the matrix ore zone. Also, some massive sulphide veins were found within the Footwall sequence due to remobilisation of sulphides by metamorphic events. This footwall mineralisation is situated inside altered zones, which are located along the contact basal portion of PUC.
- The ultramafic rock samples are mostly derived from extremely pure olivine-sulphide adcumulate/mesocumulate protolith, some of which include alteration of spinifex textured A zones and olivine-enriched cumulate B zones (also described as olivine-tremolite-chlorite rocks). Rock classification is consistent with the descriptions from Barnes et al (2011) and Gole et al (1987), and the ultramafic protoliths are now represented by a series of rocks that have been subject to later metamorphic/metasomatism alterations that may have involved Ca mobility.
- The sulpharsenides can be present in areas with high amounts of chromite. These chromitites may represent pods within cumulus olivine “layers”. However this trend does not apply to all high arsenic samples within the PUC and not all samples with high arsenic also contains high chromium values.

5. PETROLOGY AND MINERALOGY OF THE PERSEVERANCE DEPOSIT

The petrological and mineralogical observations were made on rocks from two main zones of the study area: the footwall rocks (composed of volcanic/sub volcanic and sedimentary units) and the ultramafic rocks of the Perseverance Ultramafic Complex (PUC). The rocks described in this chapter are metamorphosed) and the prefix “meta” is implied but not used. Figure 5.1 shows the distribution of the geological units in the area. The footwall units can be divided from west to east (normal stratigraphical sequence) as: mafic rocks (amphibolites); sedimentary rocks (psammitic and pelitic rocks), and volcanic/sub volcanic intermediate rocks (rhyodacites). The contact between the footwall sequence and PUC is commonly demarcated by the presence of a mylonitic zone, which is shown on Figure 5.1. This chapter provides descriptions of each of the rock types identified in the study area, except for the dolerite dykes and actinolite-sulphide schists. Descriptions of each individual sample and mineral percentages are included in Appendix 3. Some mineral types, particularly the serpentine mineral series (mainly lizardite) and carbonates (dolomite, calcite, magnesite and siderite), were identified and/or confirmed by XRD analyses (Appendix 1). Table 5.1 contains the list of abbreviations used:

Table 5.1 List of abbreviations used in the petrological studies

Abbreviation	Description
C-XX	sample number (core slab)
H-XX	sample number (hand sample)
TL.XP	transmitted section with crossed polarized light
TL.PP	transmitted section plain polarized light
RL.PP	reflected light section with plain polarized light
RL.XP	reflected light section with crossed polarized light
SEM BSI	electron microscopy image with back scattered image

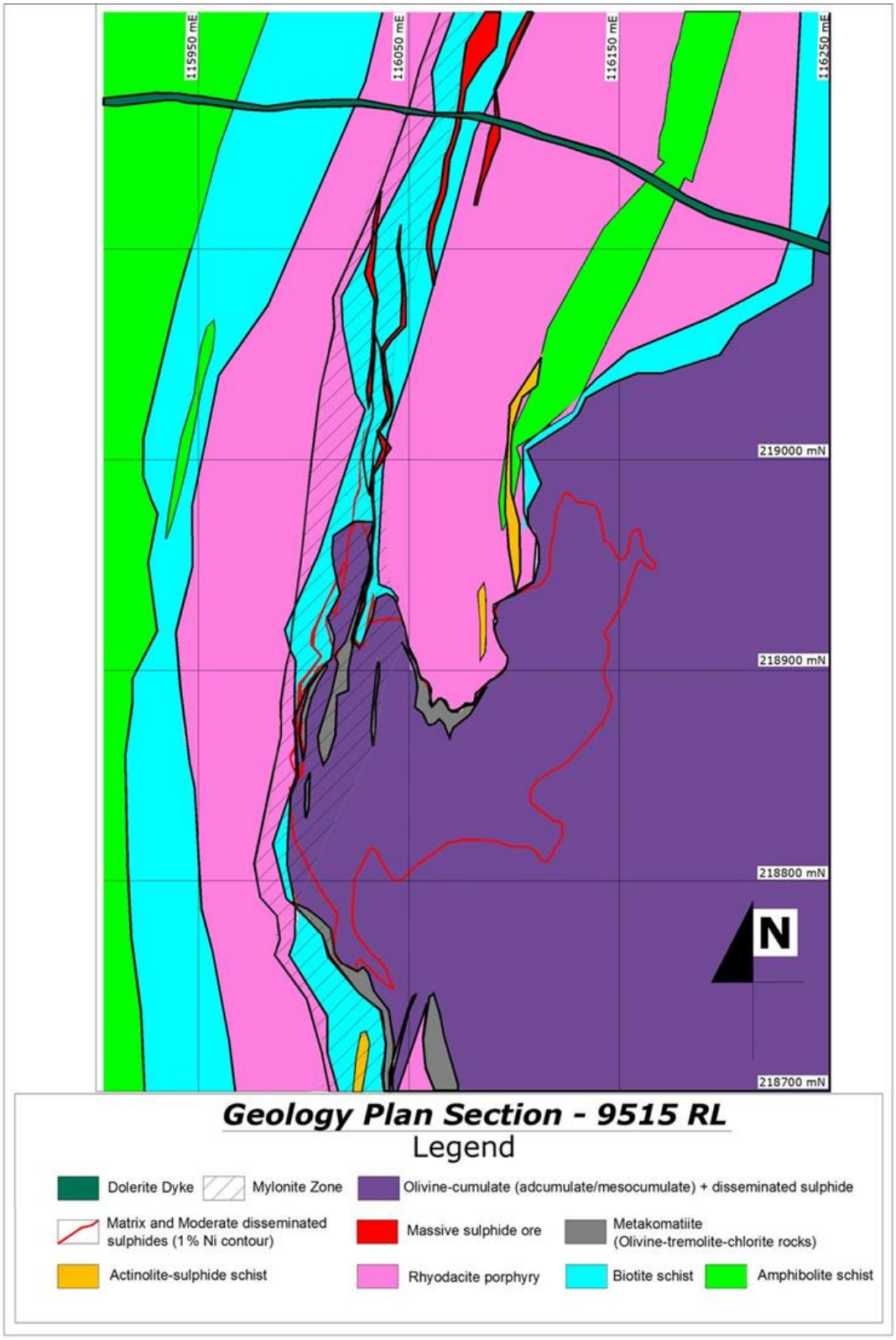


Figure 5.1. - Simplified geological plan section of the Perseverance deposit at 9515 RL (approximately 1,000m below present surface erosion) showing the distribution of geological units and the main nickel sulphide ore body (main disseminated orebody defined by the 1% Ni cut-off at the base of PUC, also described as “matrix and heavily disseminated sulphide ore”). North shown on the map is on the mine grid, which is rotated 19º 35’ 46” West of True North and 20º40’ 00” West of MGA Zone 50 Grid North.

5.1. Footwall Rocks

The footwall rocks in the study area that are located around the high arsenic areas of the deposit consist of mafic volcanic rocks, rhyodacite porphyry, psammitic and pelitic rocks (schists), which are described below:

5.1.1. Amphibolite schist (C-54, C-55, C-59)

This is the western most formation in the study area (Figure 5.1) and occurs in small pods in the biotite rich units and along the eastern limb of the felsic nose.

The amphibolite schist is largely composed of non-oriented green hornblende with partly recrystallised aggregates and lenses of variably oriented amphibole, which is mainly tremolite and minor hornblende (Figure 5.2). Very few samples containing unaltered plagioclase were found, as most of the plagioclase is altered to sericite. There is rare chlorite, carbonate (mostly occurring within late stage veins), granular titanite and small veins of interstitial quartz. Coarse-grained amphibole (most likely anthophyllite) with grain size ranging from 10–15 mm long occurs on and close to the edge of the amphibole-rich zone. Rare titanite is disseminated through the hornblende and former plagioclase-rich areas.

Some rock samples (e.g. C-59) are largely fine grained foliated schist with intercalations of white veins, mostly composed of quartz, oblique to the foliation. The rock is mostly finely foliated, up to 300 microns long quartz crystals, with abundant coarse quartz in lamellae with partially altered albite and epidote. There is minor altered biotite and accessory apatite and elongate garnet grains almost 10 mm long. The oblique veins are as much as 2 mm wide with some en-echelon offsetting and are mostly filled by prehnite and less abundant quartz, but one vein also has minor chlorite and a patch of sulphide.

Figure 5.2. - Photomicrograph of fine-grained compact, pale tremolite-actinolite schist (bottom) in contact with band consisting of an intergrowth of biotite (bi), euhedral green hornblende (ho), with green anhedral tourmaline (to) crystals, sample C-59 TL.XP.

5.1.2. Meta-sedimentary formation, biotite-schists (C-04, C-05, C-13, C-53, C-57)

This unit is composed mainly of pelitic and psammitic rocks and lies between the mafic units (to the west of the study area) and the rhyodacite porphyry unit in the footwall zone and along the contact between the ultramafic complex (komatiite unit) and the country rocks (biotite schist in Figure 5.1). Samples C-04 and C-53 are laminated siltstone or metamorphosed very fine-grained sandstone. Some areas show micromosaic quartz grains (50 to 100 microns). Mostly plagioclase is fine-grained and sericitised. Biotite is partly altered to chlorite (Figure 5.3). There are some areas that contain a very fine-grained ground mass of epidote and traces of prismatic tourmaline. The only sulphide present is rare pyrite. Chlorite-bearing zones are present and there are also a few layer-parallel lenses rich in inequigranular quartz, with muscovite in and adjacent to the lenses, mostly parallel to the layering and probably representing boudinaged veins (based on textures from Yardley, 1993).

Figure 5.3. - Photomicrograph of a quartz-feldspathic (qf) micromosaic with biotite (bi) and accessory plagioclase. Sample C-57, (TL.XP).

5.1.3. Rhyodacite porphyry (C56, C-58)

This rock contains elongate lenses 7-10 mm long composed of clear or sericite-clouded plagioclase, microcline and quartz. Muscovite is present within grains less than 0.5 mm long. The groundmass is quartz-plagioclase micromosaic with biotite as an accessory (disseminated and in lenses), which is considered likely to represent igneous mafic phenocrysts. Muscovite and/or sericite crystals are disseminated and there are minor traces of microcrystalline sulphide (pyrite). These rocks possibly represent metamorphosed quartz-feldspar-porphyritic volcanic or sub-volcanic material with re-crystallised phenocrysts. C-56 also contains disseminated fine-grained biotite in addition to the phases mentioned above. Common boudins of quartz (~10 % mode, 1 mm to 10 mm) occur rimmed by or inter-grown with garnet of various sizes to about 8–10 mm (Figure 5.4), partly within and adjacent to quartz-rich boudins. This rock represents a rhyodacite that has been affected by stress in mylonite zones.

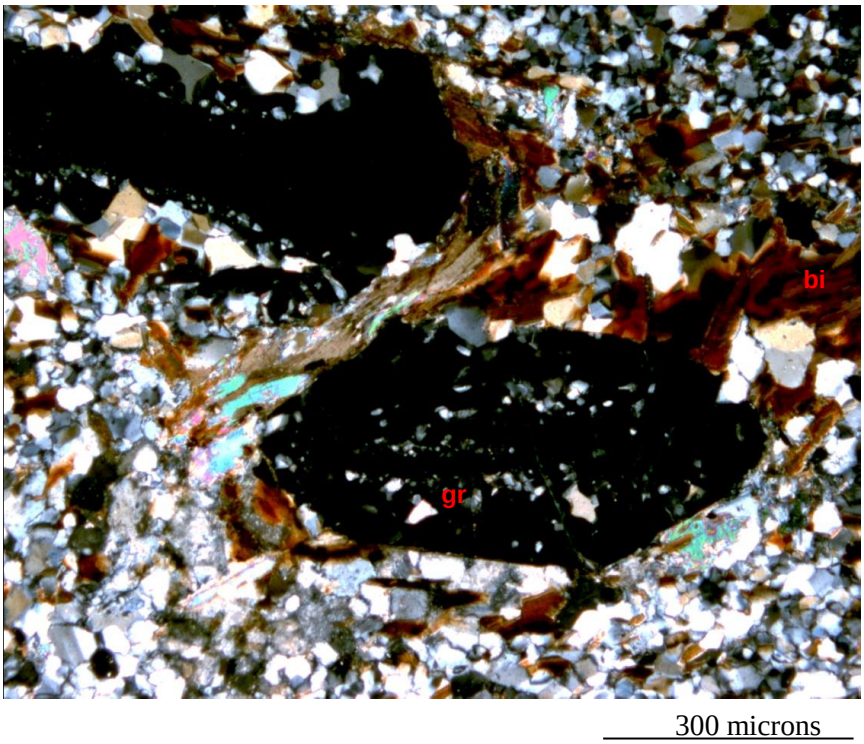


Figure 5.4. - Photomicrograph of quartz-feldspar-biotite schist with sub-equant garnet (gr) porphyroblasts with associated grains of black opaque sulphide, adjacent to biotite (bi) rich shadow zone. Sample C-56, TL. XP.

5.2 Perseverance Ultramafic Complex

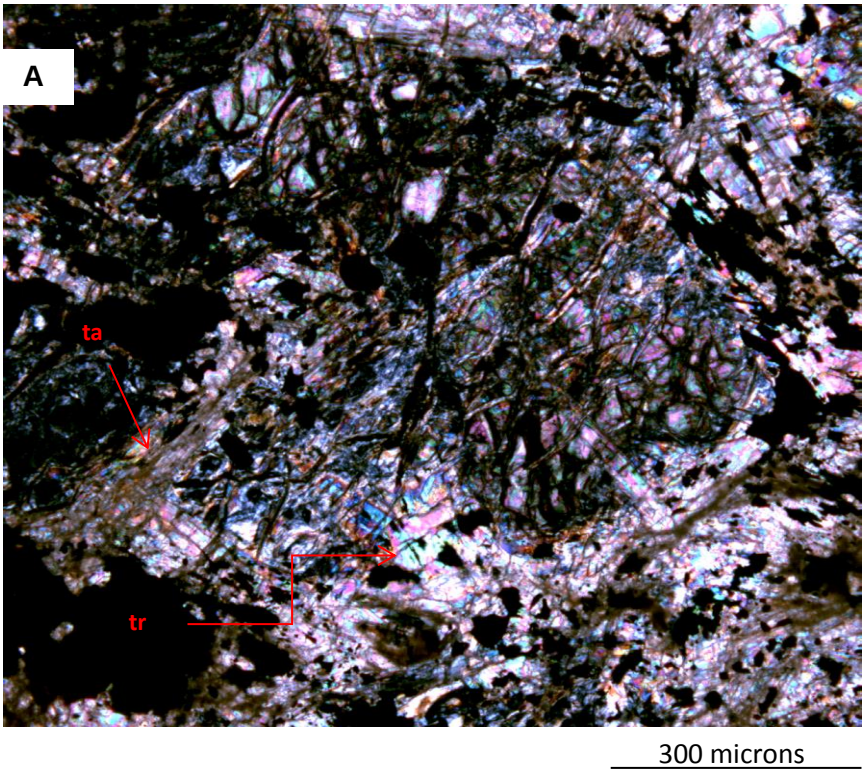
The Perseverance Ultramafic Complex contains a series of ultramafic komatiite rocks that are classified according to sulphide mineral content, and, to a lesser extent, the types of metamorphism/alteration which relate to the primary magmatic rocks. The occurrences of these rock types in the study area can be grouped following the criteria from Chapter 2 (section 2.2.1, 2.2.2 and 2.2.4) and Chapter 4 (section 4.4). They have been divided into: Olivine-tremolite-chlorite rocks corresponding to metamorphosed komatiite flows, with variation in present olivine content reflecting an original alternation of spinifex textured A zones and olivine-enriched cumulate B-zones: classification from Gole et al, 1987; Massive sulphide (which includes massive sulphide with brecciated rocks); Matrix and disseminated sulphide olivine-cumulate; Olivine-adcumulate with minor sulphide; PUC basal contact (mylonitic zone), and serpentinised olivine-cumulate sulphide rock. The sub-division of the ultramafic units described below also includes some alteration features (metamorphic or weathering) for the olivine-sulphide adcumulate and orthocumulate komatiite types. No primary fresh adcumulate komatiite (unaltered

or affected by metamorphism) has been included in the sample selection due to its lack of association with arsenic-bearing minerals.

5.2.1 Tremolite-chlorite-olivine rocks (C-15, C-19, C-22, C-23, C26, C-30, C-32, C-33, C-41 and C-50)

Olivine-tremolite-chlorite rocks are pale green and may have a schistose foliation. These rocks tend to occur towards the western contact of the PUC, which occur closer to the basal contact of PUC. They are present in the flanking rocks on either side of the ore zone (1% Ni contour and within a zone of protomylonite on the eastern margin that is closely associated with the main orebody, Figure 5.1). The tremolite-chlorite-rocks show abundant tremolite occurring as fan-like aggregates or as garbenschiefer bundles that reach a maximum of 10 mm long, and are associated with minor interstitial microcrystalline talc (Figure 5.5A). Sparsely disseminated small (10 to 30 microns) flakes of a platy mineral (most likely phlogopite) and aggregates of chlorite (clinochlore is consistent with the XRD analyses) are disseminated between tremolite and minor olivine grains and they represent an alteration of spinifex textured A zones (samples C-19, C-22, C-30 and C-50).

Olivine rich samples are mainly composed of elongated metamorphic olivines, ranging from 0.5 mm to 4 mm in length. Greater modes of olivine are taken to indicate a possible altered olivine-enriched cumulate B zone (samples C-15, C-26, C-32 and C-33). Sulphides are present as patchy zones, heavily disseminated in the matrix, and in massive sulphide veins/pods. The mineralogy of the massive veins/pods is dominated by pyrrhotite and pentlandite with overall modes ranging from 12 to 60 % and averaging 30%. Gersdorffite and pyrite are common accessory minerals (Figure 5.5 B). These rocks have been affected by prograde alteration during peak metamorphism (Gole et al, 1987) and the magmatic textures are now all overprinted by metamorphic minerals.



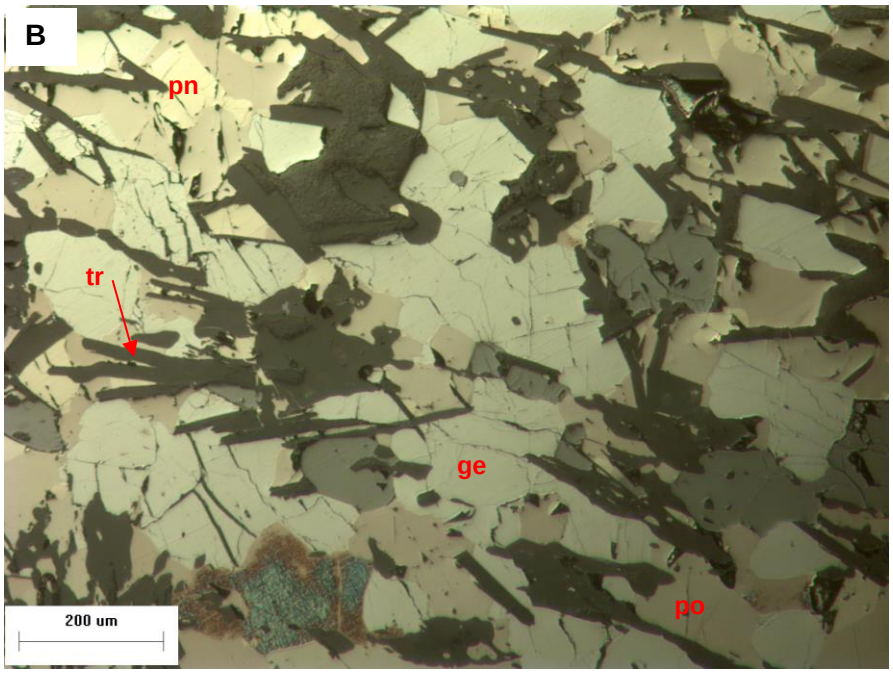


Figure 5.5. - A -Photomicrograph of abundant tremolite (tr) as fan-like aggregates or as garbenschiefer bundles, a maximum of 3 mm long (centre and lower right corner of the picture), associated with minor interstitial microcrystalline talc (ta). Sample C-30, TL. XP. B -Photomicrograph of coarse gersdorffite (ge - white minerals 75 to 250 um long) in pyrrhotite (po) rich massive sulphide area with inclusions of pentlandite (pn) and tremolite (tr) needles, sample C-50, RL.PP.

5.2.1.1 Tremolite-chlorite-olivine rocks with carbonate rich zones (C-25, C-28, C-29, C-37 and C-47)

These rocks are ubiquitous in the arsenic-rich zones of the deposit and range from fine (from 10 to 20 microns) to coarse grained rocks (grain size up to 200 microns). C-25, C-28, C-29, C-37 and C-47 are all examples of altered spinifex textured zone A. Prismatic tremolite-actinolite constitutes up to 40 % (e.g. C-28) of the sample mode. A common feature is tremolite fan-like aggregates and rosettes up to 8 mm in diameter, and less abundant isolated, partly bent prisms or fine aggregates of microcrystalline tremolite (from 20 to 40 microns), partially altered to talc or mesh-textured formed by later serpentine (Figure 5.6). These occur locally with granular metamorphic olivine (up to a maximum of 8% in sample C-37. There is approximately 1–5 % talc and 5–15 % serpentine in all samples. Serpentine is clouded with cryptocrystalline opaque Fe oxides, with later serpentine-filled microfissures richer in cryptocrystalline opaque magnetite and sulphides. Carbonates are mainly dolomite and magnesite with grain size between 50 and 150 microns (varying from 8–14 % dolomite (sample C-47), and up to 11 % magnesite) with minor calcite mostly at 1 % and up to 8 %, C-29 (Figure 5.7). Carbonates concentrate along the contacts with massive sulphide zones, where there is complete replacement of silicate minerals. The carbonate replacement is interpreted as the product of CO_2 metasomatism prior to the peak of metamorphism. Carbonate in veins is common; supporting the notion of CO_2 metasomatism (especially in sample C-47).

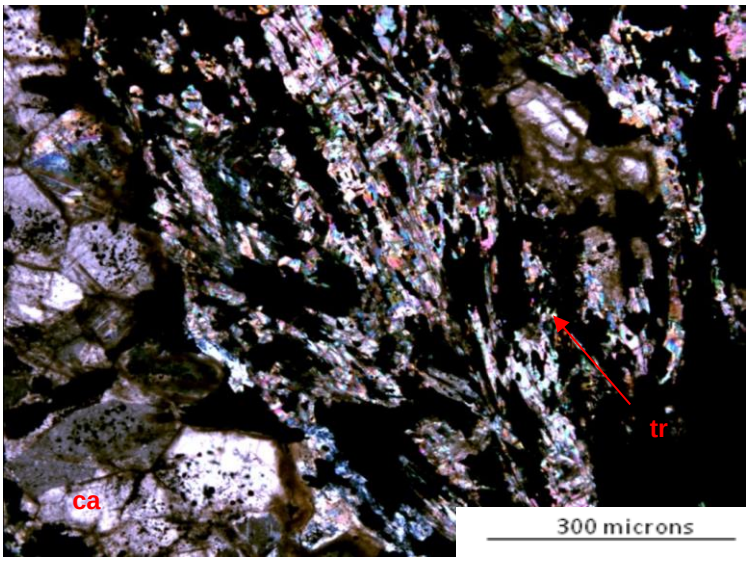


Figure 5.6. - Photomicrograph of tremolite (tr) as fan-like aggregates that are partially oriented and associated with minor interstitial sulphides (opaque minerals) and carbonate (calcite – ca), sample C-25, TL. XP.

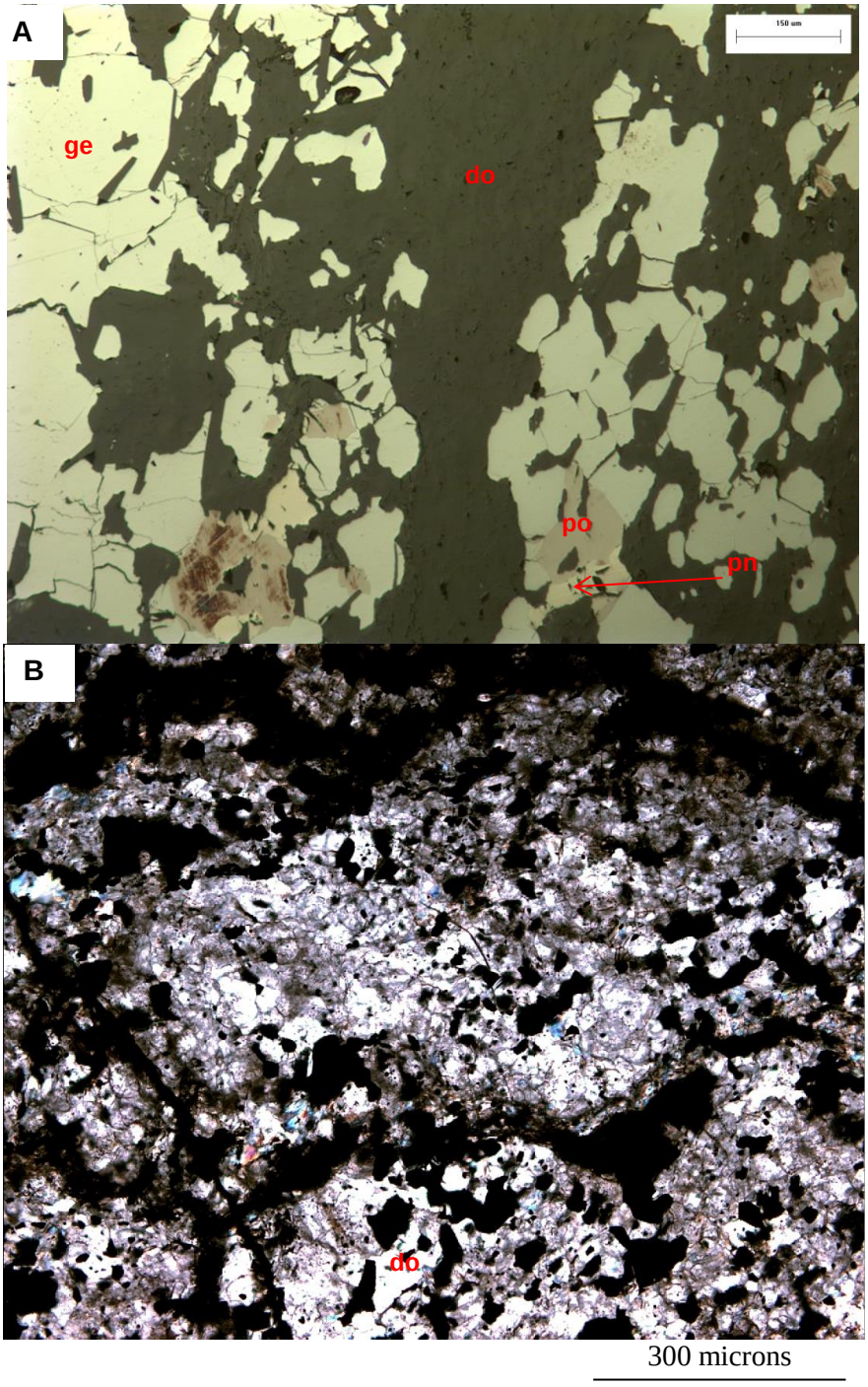


Figure 5.7. - Photomicrograph of abundant coarse gersdorffite (ge) associated with dolomite (do) vein (grey colour minerals) and minor pyrrhotite (po) and pentlandite (pn), sample C-47 RL. PP. (A), and photomicrograph of massive aggregates of dolomite and disseminated sulphide (opaque), sample C-47, TL. XP (B).

A CO_2 metasomatism event prior to peak metamorphism was also proposed by Gole et al (1987), based on textures in olivine-dolomite rocks. These workers suggested that the former presence of talc-carbonate at Perseverance is indicated by the presence of these prograde olivine-dolomite lithologies. The assemblage talc-magnesite has an upper stability limit of about 550ºC and under peak conditions at Perseverance, talc-carbonate rocks would have broken down to

either olivine-carbonate or olivine-talc assemblages (depending upon the ratio of talc to carbonate in the protolith), releasing a fluid containing five parts CO_2 to one part water (Gole et al, 1987).

5.2.2 Massive sulphide C-01, C-07, C-09, C-16, C-17, C-18, C-20, C-21, C-24, C-27, C-31, C-35, C36, C-38, C-43, C-44, C-48 and C-49)

Massive sulphides are also ubiquitous at the Perseverance deposit, where they form sheets and veins along shears at the basal portion of the olivine-cumulate sulphide ultramafic body and in small pods inside it. All the massive sulphide samples studied in detail are located in veins inside the Main Orebody; no samples were selected from remobilized massive sulphide orebodies (e.g. 1A and F2) because As in these regions has already been investigated. The most common assemblage is that of a pyrrhotite matrix with pentlandite (Figure 5.8). The pyrrhotite occurs in association with pentlandite in a range of different textures and sizes and these samples have a variable modal grain size of around 3 mm and in other cases of less than 1 mm and contain inclusions of other rocks (e.g. ultramafic, felsic), especially along brecciated zones (mylonitic contact). Magmatic textures are not clearly preserved and it is very common to observe secondary re-crystallisation of pentlandite texture based from Ramdohr, 1980), as coarse as 7 mm in grain size, with blocky and/or rounded shapes (Figure 5.8). Small flame like textures (Figure 5.9 and 5.11) are present and they represent the re-equilibration by cooling of sulphides crystallized from a sulphide melt. The largest pentlandite crystals are found in veins in lenses up to 3 mm long, (e.g. samples C-21 (Figure 5.8) and C-31).

Figure 5.8. - Core slab of massive sulphide with pyrrhotite (po) matrix and coarse recrystallised pentlandite (pn). Diamond hole 949-44, sample C-21

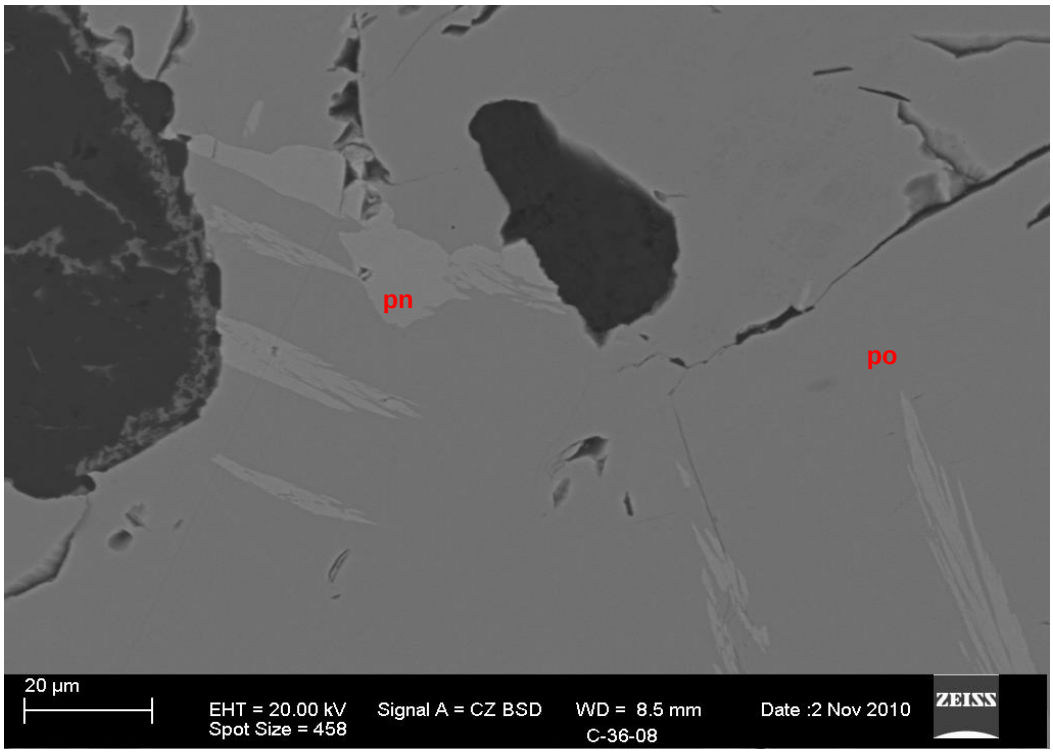


Figure 5.9. - SEM BSI showing massive pyrrhotite (po) with exsolution of pentlandite (pn) with flame like structure, sample C-36.

Magnetite is generally not very common and occurs as granular euhedral to sub-euhedral grains (up to maximum of approximately 80 microns), generally disseminated or as alteration in sulphide. It is most commonly associated with pentlandite alteration, where it occurs as a filling material in veins or along the edges of chromite. However, some examples of massive sulphide have magnetite and chromite as common minerals (e.g. C-18, C-35 and C-36), C-35 is shown in Figure 5.10, where chromite and magnetite constitute approximately 5–7 % of the sample. Chromite in C-18 and C-35 is very coarse grained (up to 300 microns) and forms layers of 3–4 mm in width and 2.5 cm in length. Disseminated chromite occurs in the pyrrhotite-rich zones and in some cases it forms small but massive layers that can be partially brecciated and associated with later carbonate minerals. Magnetite is commonly found rimming some of the chromite grains. Rare traces of sphalerite occur (C-31, C-43 and C-48) and gersdorffite can be present in some parts of the study area as a common mineral (C-09, C-18, C-24, C-31, C-35, C-36, C-38 and C-49), where it displays a rounded shape, or as small inclusions in other sulphides. Gersdorffite is also present as coarse blocky crystals to a maximum of 0.3 mm (e.g. C-38, Figure 5.12). Chalcopyrite only occurs in trace quantities (max of 1%, C-09) and is generally found rimming intergrowths of pentlandite and magnetite aggregates. There are traces of pyrite; in some samples (C-07 and C-09) pyrite occurs as round to elliptical grains and comprises up to

20% of sulphide mineral content. These pyrite grains are very bright with no clear signs of alteration.

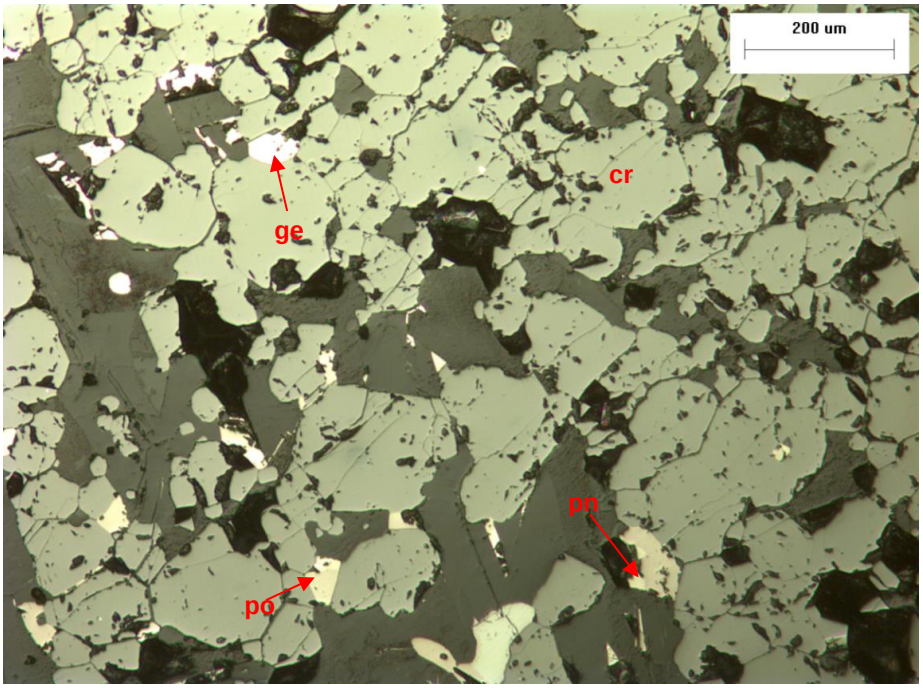


Figure 5.10. - Photomicrograph of coarse chromite (cr) rich zone partially replaced by magnetite with gersdorffite intergrown (ge), and minor scattered pyrrhotite (po) with inclusions of pentlandite (pn), C-35, RL. PP.

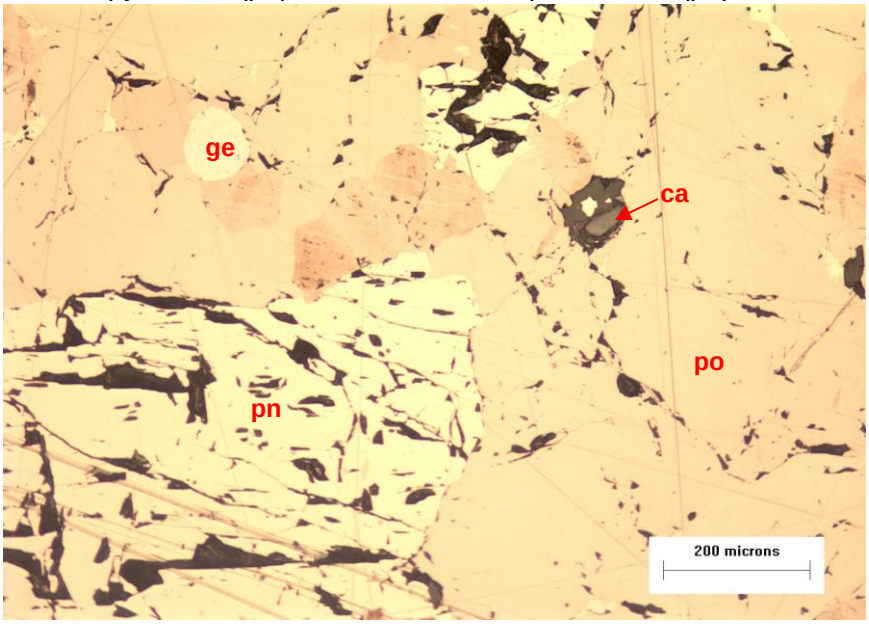


Figure 5.11. - Photomicrograph of coarse pentlandite (pn) with yellow colour and strong cleavages, small inclusions (flame like structures) inside pyrrhotite (po) matrix. The section also contains round white gersdorffite (ge) and an approximately 75 microns carbonate grain (ca), C-09, RL. PP.

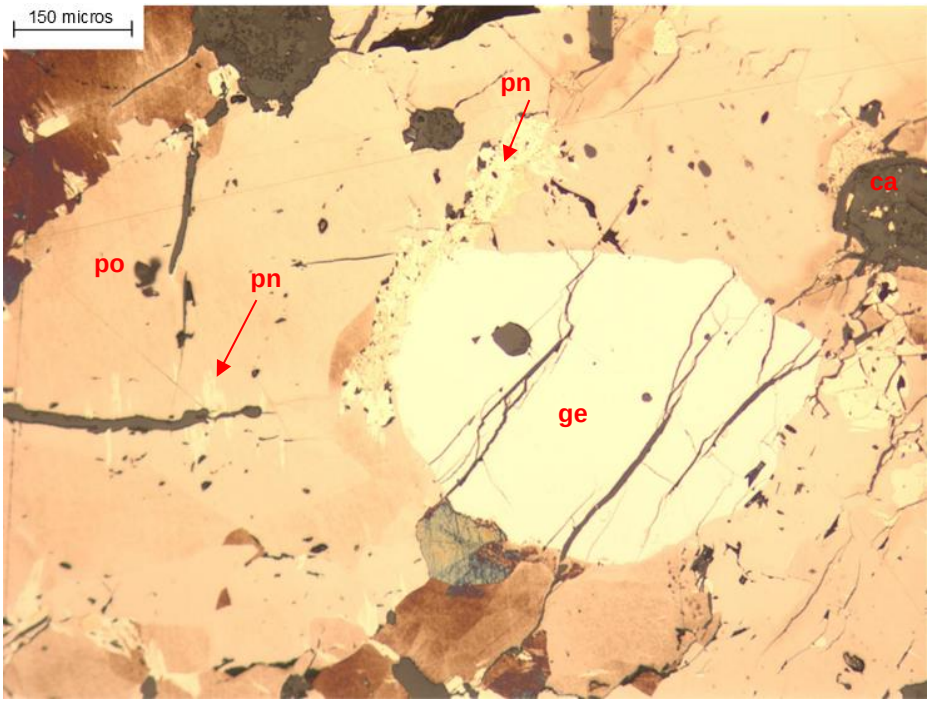


Figure 5.12. - Photomicrograph of coarse partially rounded grain of gersdorffite (ge) in pyrrhotite (po) with purple oxidation and recrystallised metamorphic pentlandite (pn) in micro veins or as flame like textures with small scattered carbonate grains (ca), sample C-38, RL. PP.

5.2.3 Matrix and disseminated sulphide olivine-cumulate (C-03, C-39, C-45 and C-46)

In the olivine-cumulate sulphide rocks (matrix and disseminated sulphide-rich) the main silicate mineral is olivine, which is mostly metamorphic in the study area. Olivine comprises up to 57 % of the mode and ranges from 0.5 mm to 4 mm in grainsize (Figure 5.13A), with discrete areas that contain bladed olivine up to 6 mm in length. The bladed olivines are interpreted to have been produced by metamorphism of serpentine formed prior to peak metamorphism. There is a large variation in anthophyllite contents, with distinct anthophyllite-rich zones, which typically comprise sub-parallel aggregates of coarse to very coarse-grains ranging from 10 mm to 15 mm long and up to 4 mm wide, samples C-45 (Figure 5.13) and C-46. There are quite high amounts of texturally late serpentine (up to 22% of the mode) and they may record a gradational weathering profile as described in Barnes et al (2011) and these serpentinised rocks are described individually in section 5.2.6. The anthophyllite, like the olivine, has been interpreted as the product of prograde alteration resulting from peak metamorphism (Gole et al, 1987). The olivine-cumulate sulphide rock (matrix and heavily disseminated sulphide-rich) represents the bulk of the resource at Perseverance deposit and the main sulphide is pyrrhotite, which occurs in association with pentlandite. However,

most of the mineralisation is held by serpentinised rock in the study area (section 5.2.6).

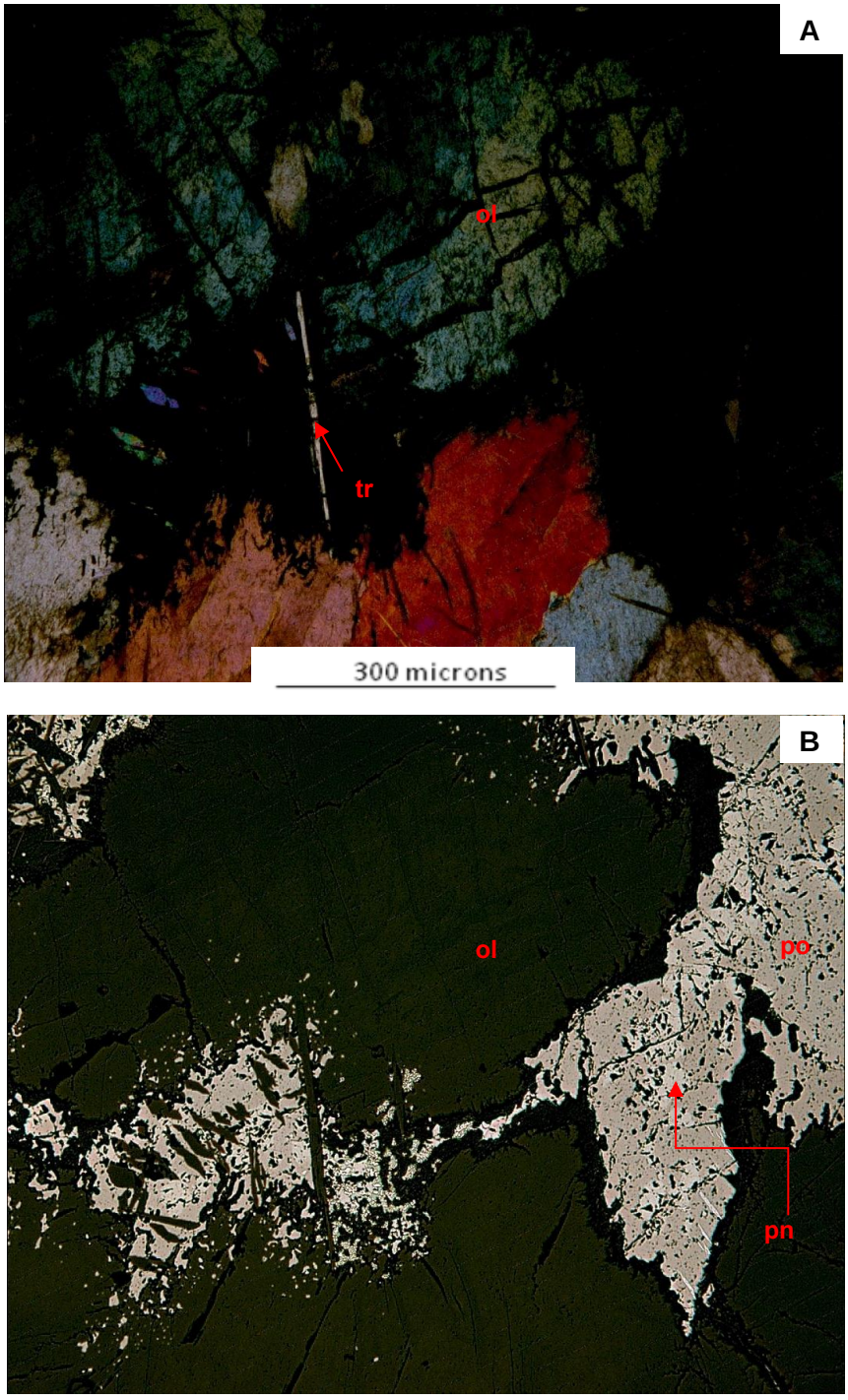


Figure 5.13.- Photomicrographs of aggregates of partially altered coarse metamorphic olivine (ol) with minor magnetite rimming the grains and tremolite (tr) with disseminated pyrrhotite (po) and pentlandite (pn). Sample C-03, A (TL. XP) and B (RL . PP).

Pyrrhotite and pentlandite form aggregates or patchy zones heavily disseminated in the matrix, and in massive sulphide veins/pods up to 0.5mm in diameter, with trace pyrite and some magnetite that fills micro veins. Magnetite also occurs as separate magnetite grains and aggregates varying from 20 to 100 microns. Sulphide textures can be present as small flame like textures involving pyrrhotite and pentlandite, but the sulphides are commonly “filling” the spaces between the “bladed” metamorphic olivine. Gersdorffite is small (75–100 microns) and occurs in trace quantities in C-45.

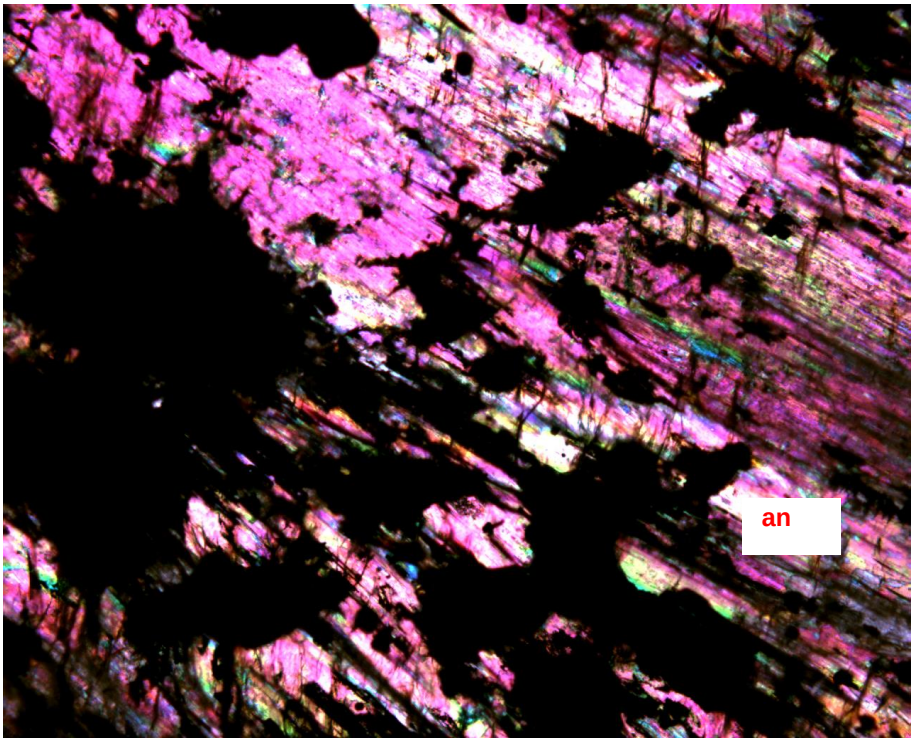


Figure 5.14. - Photomicrograph of very coarse anthophyllite (an) crystal with pyrrhotite and pentlandite inclusions (opaques) sample C-45, TL, XP.

5.2.3.1 Altered matrix and disseminated sulphide olivine-cumulate rock with carbonate rich zones (C-11, C-14 and C-42)

Olivine-sulphide cumulate rocks with carbonate rich zones are also distinguished by the presence of heavily disseminated matrix and massive sulphide veins, mostly pyrrhotite and pentlandite (with minor chalcopyrite and pyrite). The main sulpharsenide is gersdorffite, which is fine to very coarse grained (from 10 to 500 microns), and well recrystallised in veins (e.g. C-14 features veins up to 1 cm thick transecting the entire sample, LTK60 core, which is 4.52 cm diameter and on C-14 Figure 5.15).

In some instances, minor cobaltite traces can be found along the edges of gersdorffite crystals (Figure 5.16). In other cases, sulphide minerals are combined with magnetite and they also occur in a disseminated texture. Gersdorffite is ubiquitous throughout the samples with small to coarse grains, 2–3 mm in size and it occurs preferentially in the carbonate rich alteration veins. Carbonate is mainly calcite (varying from 6–10 %) with minor dolomite (trace) and up to 3 % in C-42. Carbonates concentrate mostly along the contacts with massive sulphide zones.

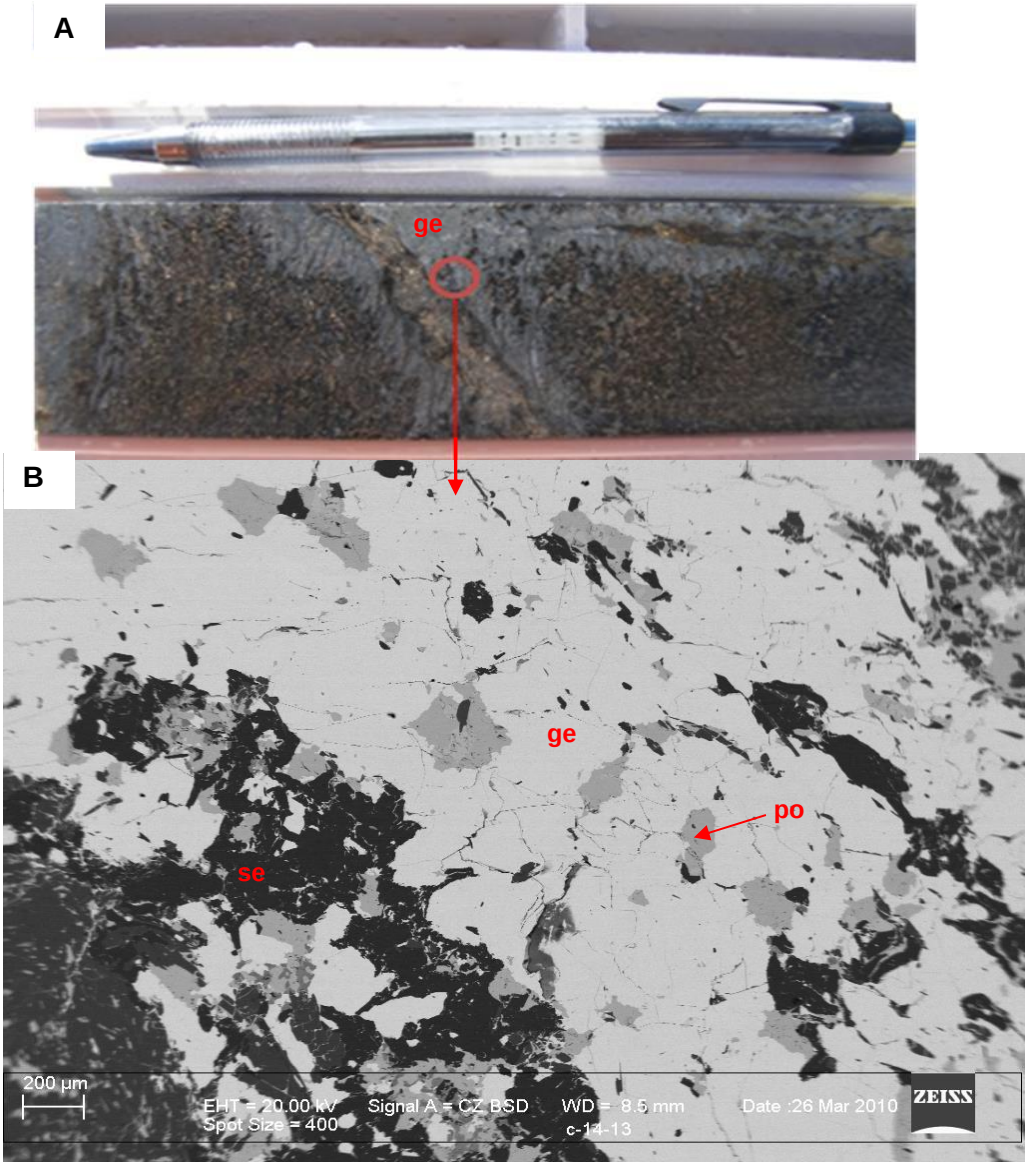


Figure 5.15. - A- Photo of diamond drill core LTK-60 diameter (C-14) showing shear zone with gersdorffite replacing sulphide minerals. B - (C-14): SEM back scattered image from the area circled in the core slab (A) along the shear zone. Note the presence of inclusions of pyrrhotite (po) and gangue (tremolite) and serpentine (se) along the edge of gersdorffite matrix.

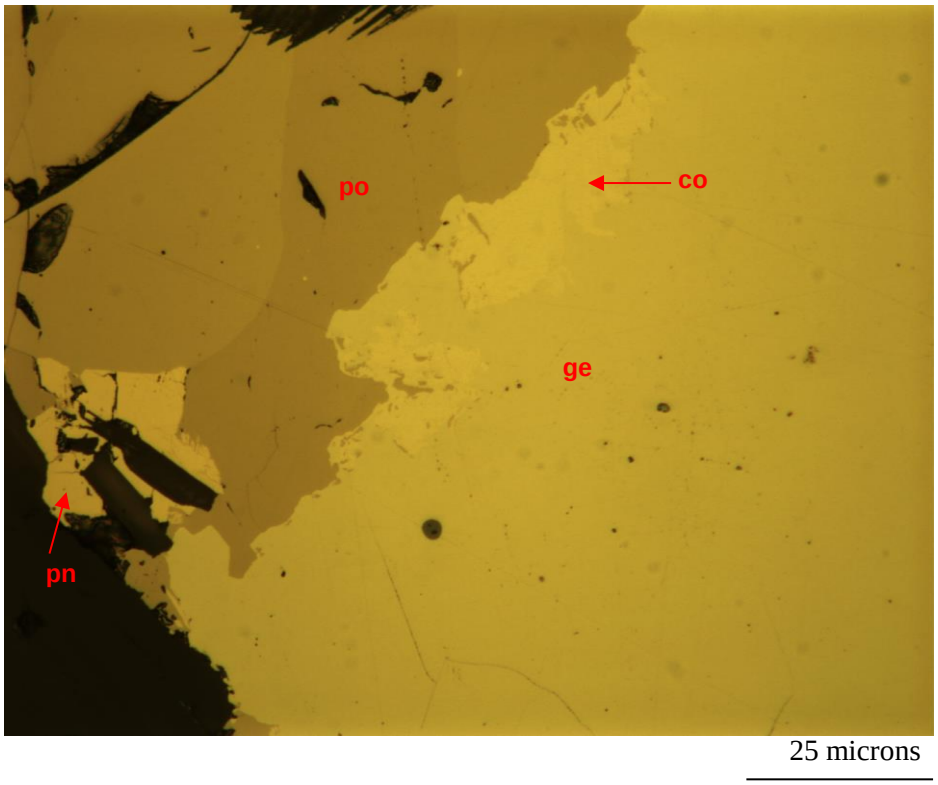


Figure 5.16. - Photomicrograph of coarse gersdorffite (ge) in pyrrhotite (po) matrix with inclusions of pentlandite (pn) and cobaltite (co) rimming gersdorffite, sample C-14, RL. PP.

5.2.4 Olivine-adcumulate with sulphides (C-60 and C-61)

These rock types are characterized by having more than 90% olivine in the mode (dunite, samples C-60 and C-61). The olivine crystals are relatively massive, metamorphic and range from 0.2 mm to 2 mm in grain size, with some areas containing olivine up to 6 mm long (Figure 5.17). Chlorite is disseminated as flakes up to 1 mm in size, positioned in and between olivine grains and makes up 3 to 5 % of the mode. Sulphides are commonly disseminated, but also form small aggregates, in which individual grains can be up to 1.5 mm long and 1 mm in diameter. Sulphide modes vary from trace to 7 % of the total mode. Rare ferri-chromite is present. The sulphide aggregates vary from pyrrhotite-rich to millerite-rich with rare pentlandite. Some millerite grains contain irregular unidentified lamellae. Samples contain minor serpentine (varying from trace to 5 %) in a network of fractures. The sample also displays fine-grained disseminated magnetite and sulphide, mainly in a disseminated texture (up to 50 microns). The

sulphide aggregates include pentlandite, pyrrhotite and trace pyrite, locally occurring with magnetite, which also features as grains and aggregates.

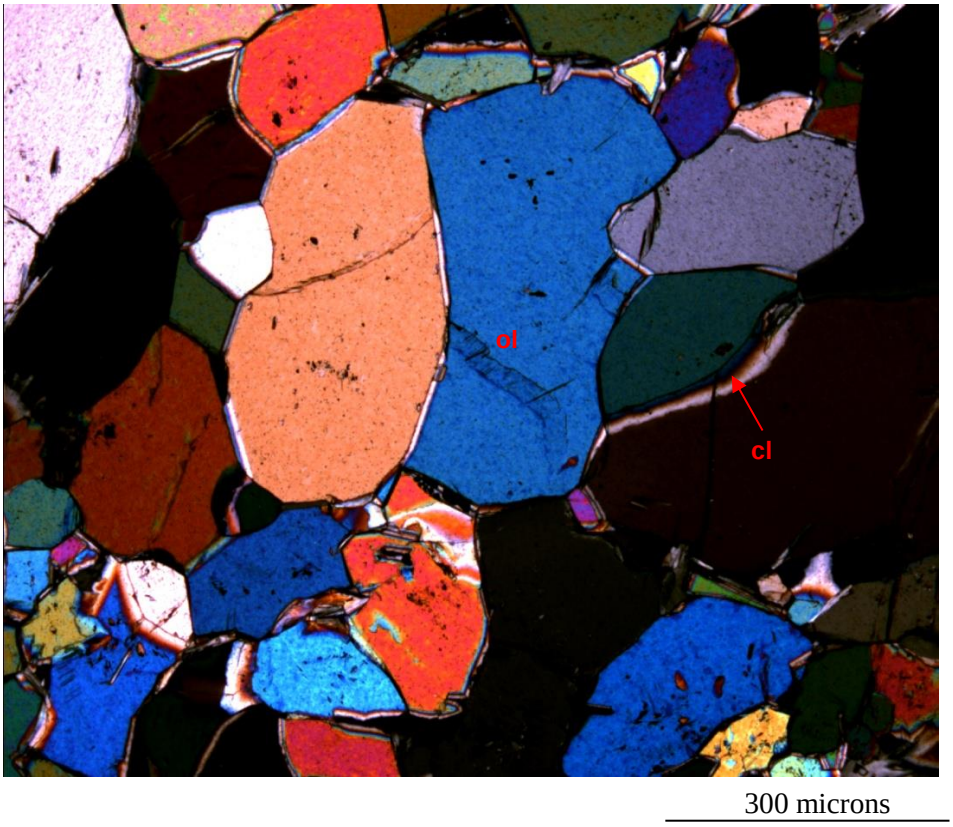


Figure 5.17. - Photomicrograph of adcumulate-olivine (dunite) with aggregate of olivine (ol) with minor chlorite (cl) riming the grains (cl is disseminated as flakes to 1mm in and between olivine grains, sample C-60 TL. XP.

5.2.5 PUC basal contact – Mylonitic zone (C-06, C-08 and H-03)

This unit is located on the contact between the Perseverance Ultramafic Complex and the country rocks, along a mylonite/sheared zone (Figure 5.18). This unit is formed from brecciated blocks that occur in a faulted zone (the blocks include felsic, ultramafic and massive sulphide rock types).

Felsic blocks are mainly rocks composed of fine-grained, elongated quartz (50 microns in diameter with modes of approximately 5 to a maximum of 10 %), and sericitised fine grained plagioclase (up to 20 to 30 microns). Trace minerals include minor biotite along the foliation, and irregular tourmaline, up to maximum of 0.2 mm in grainsize and sub parallel to the foliation. The contact zone is marked by

pyroxene (augite) partially oriented to the foliation with hornblende+biotite+chlorite aggregates and minor magnetite and pyrrhotite with small inclusions of pentlandite (as flame like texture).

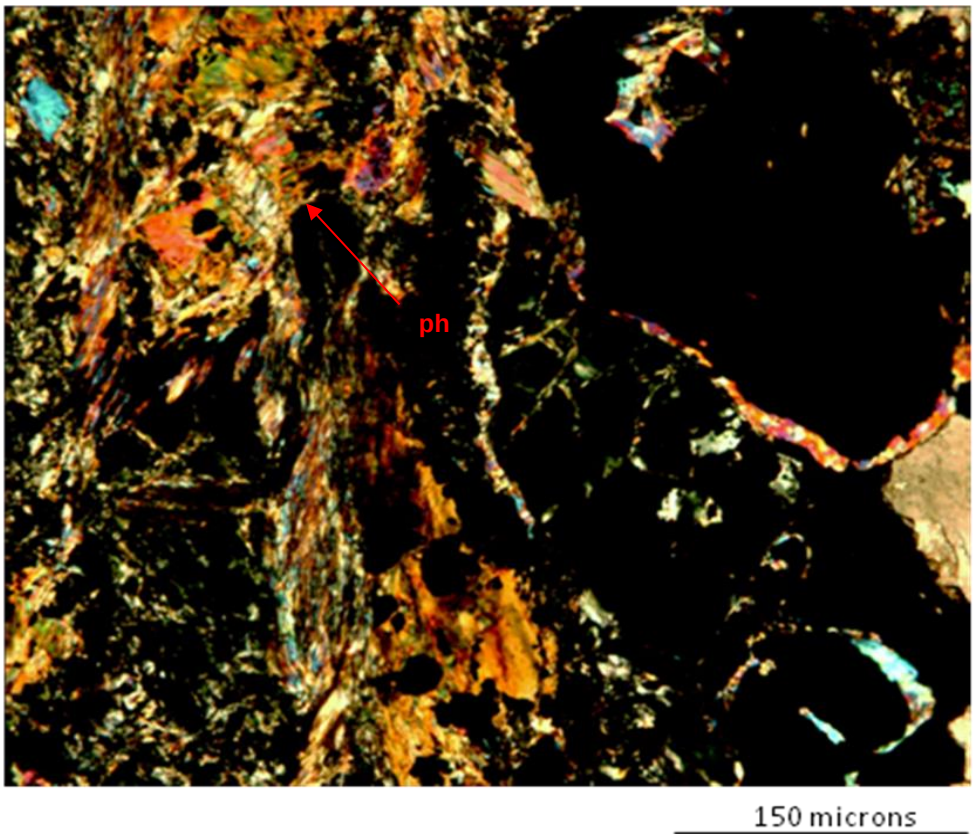


Figure 5.18. - Photomicrograph of an aggregate of partially altered coarse grained serpentine and phlogopite (ph) schist with associated sulphides (opaque mineral), sample C-08, TL. XP.

In the ultramafic blocks, the dominant minerals are coarse-grained euhedral tremolite, (kinks and small folds are seen in sample C-06) and rare metamorphic neoblastic olivine, along with chlorite+biotite+talc aggregates that are olivine and tremolite alteration products. Trace minerals include anthophyllite and serpentine (lizardite) and later veins of carbonate (calcite) along the foliation. Sulphides are typically pyrrhotite and pentlandite held in disseminated to brecciated textures. Very pervasive magnetite alteration occurs along the contact between the ultramafic and felsic rock while gersdorffite tends to concentrate along the coarse tremolite-rich zone. In sample C-06 two metamorphic events are recorded. The first is marked by tremolite and biotite growth, followed by increasing carbonate+chlorite and magnetite alteration.

5.2.6 Serpentinised olivine-cumulate sulphide rock (C-02, C-10, C-12, C-33, C-34, C-40, C-51, C-52, H-01 and H-02)

The serpentinised olivine-cumulate sulphide rock (matrix and disseminated sulphide-rich) represents the bulk of the Ni resource at the study area and it is very common in the arsenic-rich zones of the deposit. This rock type is generally located close to the mylonite zone in proximity to the basal contact. The main serpentine mineral is lizardite (confirmed by XRD analyses) and it features mesh and relict textures indicating derivation from granular metamorphic "bladed" olivine (Figure 5.19). Serpentine reaches a maximum of 3 to 5 mm grain size. Sparse fine grained pentlandite and magnetite (up to 60 microns) are disseminated in a pyrrhotite matrix in some areas within samples, and, in some cases, within micro massive sulphide veins (samples C-12, C-33 and H-01). The serpentine is clouded with opaque oxides (Figure 5.20); texturally late serpentine-filled micro-fissures are also rich in cryptocrystalline opaque magnetite and sulphides. There are occurrences of abundant magnetite-clouded mesh-textured serpentine derived from granular metamorphic olivine, and common to abundant serpentine without magnetite association as well as aggregates of anthophyllite, up to 1 mm long (sample C-34). There are also crystal aggregates up to 0.5 mm in diameter composed of magnetite that fills fractures in pyrrhotite. Coarse granular gersdorffite can be common (samples C-12 1 to 2 mm grain size, also on C-52) mostly in pyrrhotite aggregates, or it occurs rimming small inclusions, in spinel (sample C-12 and H-01).

Figure 5.19. - Typical serpentinised ultramafic komatiite with disseminated sulphides (elongated crystals of serpentine in disseminated sulphide rock). Sample H-02.

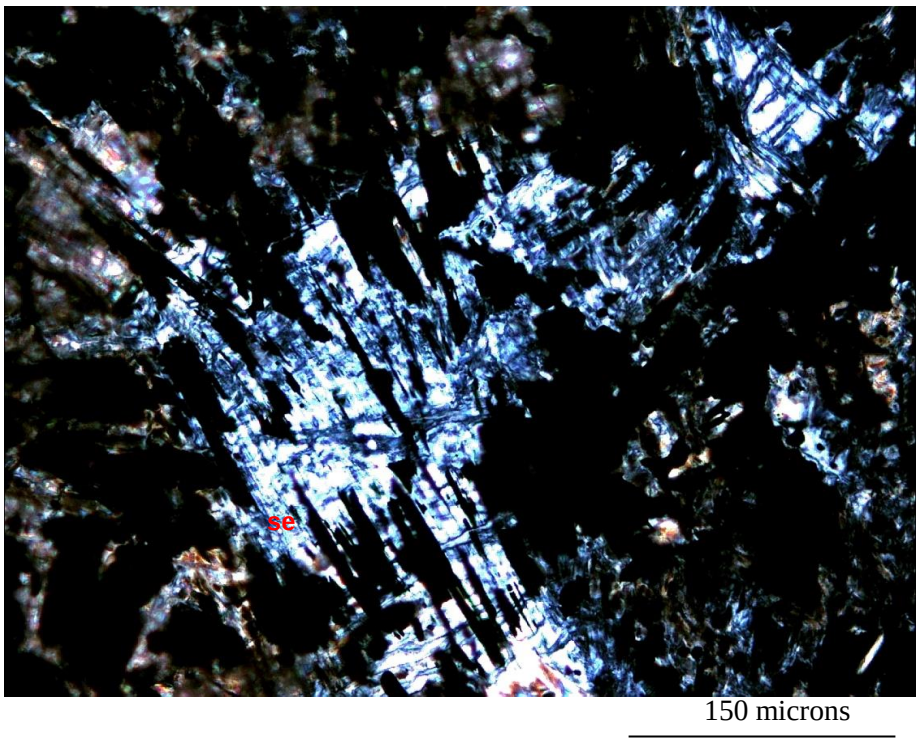


Figure 5.20. - Photomicrograph of an aggregate of partially altered coarse serpentine (se) of lizardite type, sample C-33, TL. XP.

Pyrrhotite and pentlandite are the main sulphides and they are very altered and re-crystallised, with some examples of very coarse sized blocky pentlandite (up to 400 microns) or pentlandite that fills the space between serpentine grains, which represent the alteration of “bladed” olivine grain shapes (Figure 5.22). Sulphides are partially replaced by gersdorffite of different grain sizes (from 10 up to 150 microns), microcrystalline to coarse (C-52, Figure 5.21) that are associated with carbonate alteration. Chromite is round with altered edges; grain sizes range from 10 to 70 microns (C-52). Pyrrhotite-pentlandite aggregates also have round and extremely altered margins. Minor carbonate veins (mainly calcite, most likely late) are present inside the serpentine rich zone, and can be present from micro veins (up to 1 mm thick) up to areas of up to 20 cm. Calcite is the main vein mineral and occurs as rhombohedral grains (eg C-52, Figure 5.21), in a matrix of fine grained calcite (C-10) (10 to 20 microns), or coarse well crystallised calcite (C-52), with grain size up to 200 microns. The texture is chaotic (aggregates of carbonates and serpentines) and the sulphides vary from very small and fine to coarse and blocky and they are mainly disseminated along micro veins (from 50 to 200 microns).

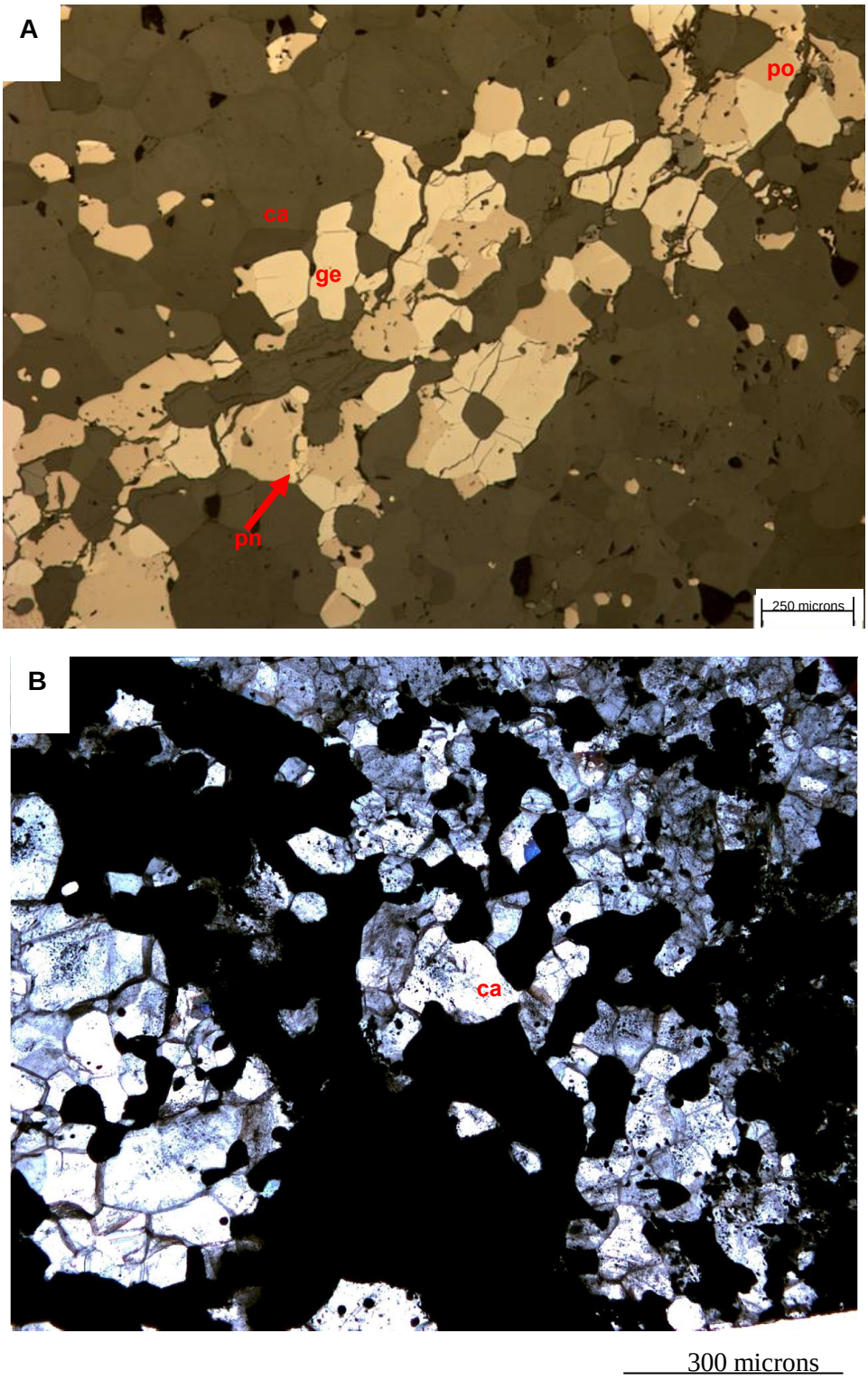


Figure 5.21. - Photomicrograph of pyrrhotite (po), pentlandite (pn) and coarse blocky gersdorffite (ge) as disseminated sulphide inside a coarse carbonate matrix (ca). Sample C-52, (A) RL.PP and (B) TL.XP.

These textures are interpreted to represent a metasomatically altered rock. The serpentine-rich zone is considered to have been subjected to post-metamorphic retrograde serpentinisation, which decreases in extent and intensity with depth below the present-day erosion surface. The retrograde serpentinisation is therefore thought to have taken place during weathering processes (Barnes et al, 2011).

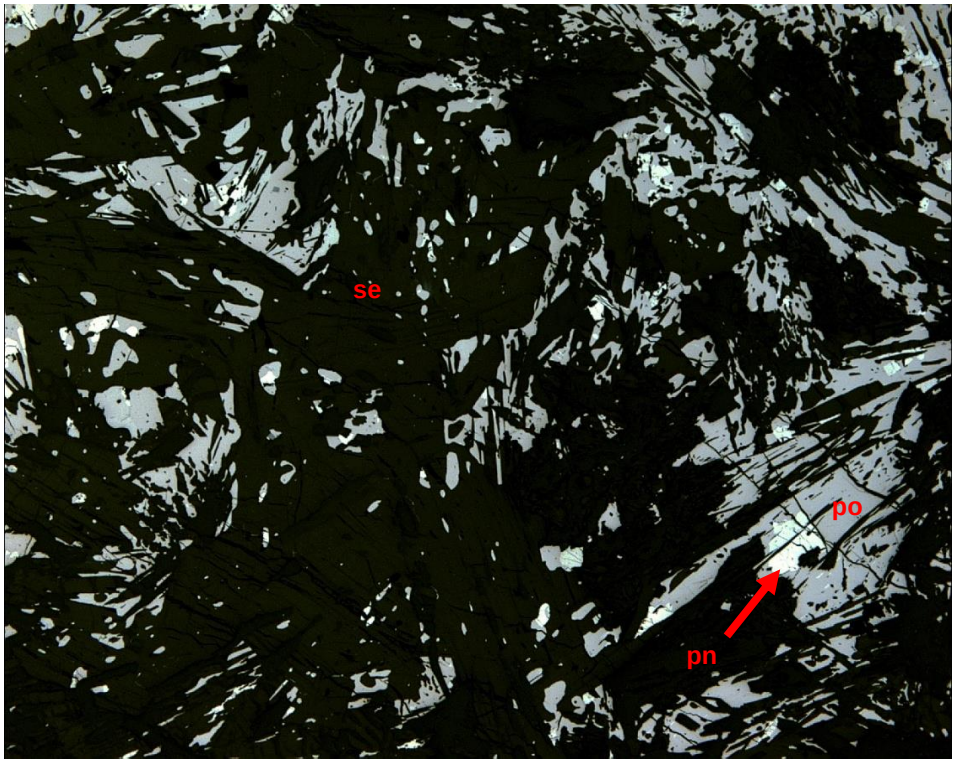


Figure 5.22. - Photomicrograph of pyrrhotite (po) with interstitial pentlandite (pn) in the serpentine (se) matrix after bladed olivine, sample C-33, RL . PP.

5.3. Summary of petrology and mineralogy at the Perseverance deposit inside the study area

- Petrological observations of the study area were made for two main zones: the footwall rocks (volcanic/sub volcanic and sedimentary units) and the ultramafic rocks of the Perseverance Ultramafic Complex.
- The footwall rocks consist of mafic volcanic rocks, rhyodacite porphyry, psammitic and pelitic rocks (schists). None of the rocks listed above

contain arsenic-bearing minerals, even in the areas of most extreme alteration that occur along the mylonite zone, with the exception of rocks contain massive sulphide that has been remobilized into the footwall sequence.

- The Perseverance Ultramafic Complex (PUC) contains ultramafic komatiite rocks that are classified according to sulphide mineral contents and the types of metamorphism/alteration related to the magmatic protolith. The occurrences of these rock types in the study area can be described as follows: Olivine-tremolite-chlorite rocks (corresponding to metamorphosed komatiite flows, the variation in present olivine content reflecting an original alternation of spinifex textured A zones and olivine-enriched cumulate B-zones, based on Gole et al, 1987), Massive sulphide (which includes massive sulphide with brecciated rocks), Matrix and disseminated sulphide olivine-cumulate rock, Olivine-adcumulate with minor sulphides, PUC basal contact (mylonitic zone) and serpentinised olivine-cumulate sulphide rock. The samples containing arsenic-bearing minerals in the PUC rocks can be divided into two groups:

Massive sulphide rocks: These rocks comprise a mostly pyrrhotite matrix with pentlandite in different textures and sizes. Magmatic textures are not preserved and are largely replaced by secondary re-crystallisation textures of blocky or rounded shape. The ratio between pyrrhotite and pentlandite is similar in all massive sulphide samples and the average is 2.2:1 (pyrrhotite/pentlandite). Gersdorffite can be found as a trace mineral with varying shape from small rounded crystals to inclusions and coarse blocky crystals. Chromite is very coarse, sub-euhedral, with the edges altered to magnetite or ferri-chromite; chromite cores are occasionally preserved. Most of the gangue minerals are located in the brecciated zones and are composed of serpentine, carbonate (mainly calcite and minor dolomite) and minor actinolite/tremolite.

Ultramafic komatiite rocks: represented by the following divisions:

- *Serpentinised ex-olivine-cumulate sulphide rock and Altered matrix and disseminated sulphide olivine-cumulate*, These rocks are found in some of the most arsenic-rich zones of the deposit and are composed of serpentine (lizardite) with sulphides present as a heavy dissemination within the matrix and/or in micro-scale massive sulphide veins, with some secondary, coarse grained

calcite and minor dolomite, or as a fine matrix. The sulphide mineralogy is mostly pyrrhotite and pentlandite with some samples having from 12 to 60% of sulphide with an average of 30% (some massive sulphide veins included). Gersdorffite is a common accessory mineral and generally replaces pyrrhotite (pyrite) or pentlandite (gersdorffite) but gersdorffite is also found as small equant or rounded grains preserved in massive pyrrhotite, or inside pentlandite and ferri-chromite. Some of the carbonate-rich samples are inferred to have been exposed to an intensive CO_2 metasomatic event. ?? prior to regional metamorphism?

- *Olivine-tremolite-chlorite rocks*: The ore minerals in this unit are pyrrhotite and pentlandite with minor chalcopyrite and pyrite. Gersdorffite is fine to coarse grained and well recrystallised in veins, with minor cobaltite along the edges of some gersdorffite crystals but also gersdorffite is found as small crystals or as round grains preserved in massive pyrrhotite, or inside pentlandite and ferri-chromite. The key oxides are magnetite and chromite and they are disseminated in pyrrhotite-rich zones. This rock type can be sub-divided into tremolite-chlorite rocks (which possibly represent altered spinifex textured A zones) and olivine-tremolite-chlorite rock (which possibly represents an altered olivine-enriched cumulate B zone). Both rocks types include carbonate-rich examples that are interpreted to have been exposed to an intensive CO_2 metasomatic event. ?? prior to regional metamorphism?

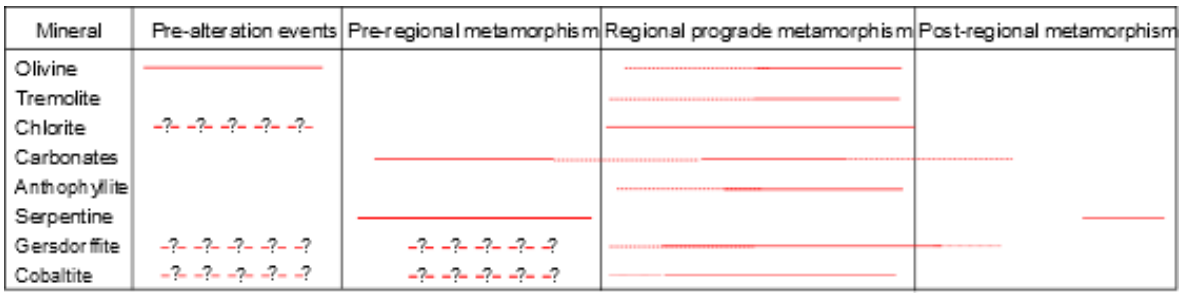


Figure 5.23. - Interpreted timing of mineral crystallisation or re-crystallisation from with respect to the main events of metamorphism, alteration and primary magmatism. Observations are valid for the PUC in the study area.

6. SULPHIDE, SULPHARSENIDE AND OXIDE COMPOSITIONS

The arsenic-bearing minerals in the Perseverance deposit are mainly related to Co-Ni-Fe sulpharsenide phases that represent the dominant arsenide mineral series of the Perseverance mineralisation.

Ni-bearing sulpharsenide minerals are the predominant type with minor Co-bearing sulpharsenides. Sulpharsenides are represented by two main minerals, gersdorffite - NiAsS and minor cobaltite - CoAsS. Identification of these mineral phases is based on reflected light microscopy and SEM microanalysis. A complete table of SEM EDS microanalysis data for the main sulphides (pyrrhotite, pentlandite and chalcopyrite), sulpharsenides (gersdorffite/cobaltite) and oxides (chromite/magnetite) is provided in Appendix 4 and the mineral textural relationships are documented in Chapter 5. Gersdorffite (ge) and cobaltite (co) are commonly associated with the following sulphide and oxide minerals:

- Pyrrhotite (po) - $Fe_{1-x}S$;
- Pentlandite (pn) - $(FeNi)_8S_9$;
- Chalcopyrite (cp) – $CuFeS_2$;
- Magnetite (mt) – Fe_3O_4;
- Chromite (cr) – $FeCr_2O_4$;
- Pyrite (py) – FeS_2

  It should be noted that pyrite is rare and was only observed in two samples and is not described in detail in the following description. Also atomic weight percentage (aw %) was converted for pyrrhotite and pentlandite samples)

6.1. Sulphides

6.1.1 Pyrrhotite

Pyrrhotite represents the dominant base-metal sulphide within the Perseverance orebody. Pyrrhotite composition varies as follows (Figure 6.1):

- Fe concentrations average 60.4% ± 1.91 wt% (n=97) or 46.22 % ± 1.27 aw%;

- S concentrations average of 40.31% ± 1.19 wt% (n=97) or 53.66% ±1.31 aw %.

Some of the analysed pyrrhotites have Ni concentrations above the detection limit (7 samples out of 98) with Ni concentrations between the detection limit of 0.48 wt% to 1.15 wt%. Ni at this level may be present as solid solution in pyrrhotite, or may be an artefact of contamination of the analytical volume by nearby pentlandite or gersdorffite crystals.

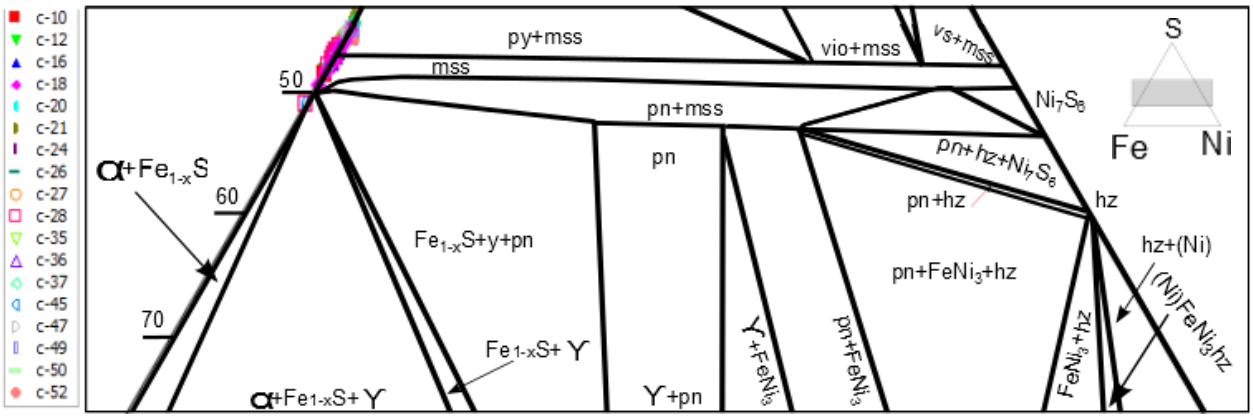


Figure 6.1. - Ternary S+Fe+Ni plot of the pyrrhotite microanalyses from SEM EDS and corrected to atomic weight %. Portion of the Fe-Ni-S isothermal section at 400 °C from Raghavan (2004) and based on Craig et al (1968). Solid solutions denoted "Y" between Fe and Ni is stable over a wide range of temperature. Abbreviations are pyrrhotite (po), pyrite (py), pentlandite (pn), heazlewoodite (hz), violarite (vio), vaesite (vs) and monosulphide solid solution (mss)

6.1.2. Pentlandite

Pentlandite represents the dominant nickel-bearing mineral within the Perseverance orebody. Pentlandite composition varies as follows (Figure 6.2):

- Fe concentrations average 31.8 wt% ± 2.05 wt% (n=86) or 25.76 ± 1.57 aw%;

- S concentrations average 34.4 wt% ± 1.31 wt% (n=86) or 48.55 ± 1.08 aw%

- Ni concentrations average 33.2 wt% ± 2.4 wt% (n=86) or 25.59 ± 1.72 aw%.

Of the 86 pentlandite analyses, only one sample had a Co content above the detection limit of 1 wt%, with a Co concentration of 1.68 wt%. However, only samples inside the high arsenic domain were included for SEM EDS analyses and not all cobalt is related to arsenic-bearing minerals across the whole deposit, so this work may not provide a comprehensive picture of Co distribution in pentlandite.

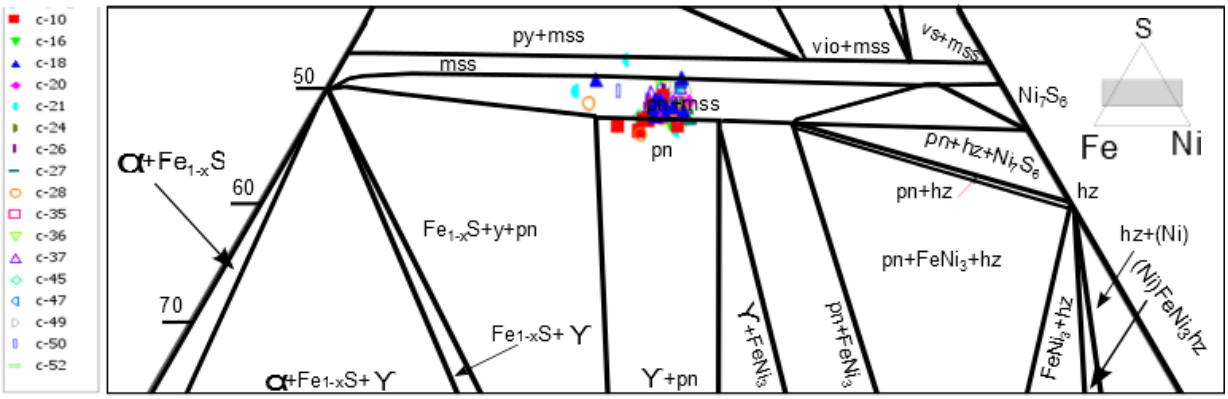


Figure 6.2. - Ternary S+Fe+Ni plot of the pentlandite microanalyses from SEM EDS and corrected to atomic weight %. Individual plots per crystal result. Portion of the Fe-Ni-S isothermal section at 400 °C from Raghavan (2004) and based on Craig et al (1968). Solid solution denoted "Y" between Fe and Ni is stable over a wide range of temperature, pyrrhotite (po), pyrite (py), pentlandite (pn), heazlewoodite (hz), violarite (vio), vaesite (vs) and monosulphide solid solution (mss)

6.1.3. Chalcopyrite

Chalcopyrite represents the only copper-bearing mineral within the Perseverance orebody. It is rare and generally occurs as small crystals, mostly located in the highly metamorphosed/altered areas of the deposit.

Chalcopyrite compositions vary little (Figure 6.3):

- Fe concentrations average of 30.2 wt% ± 0.68 wt% (n=5);
- S concentrations average 35.3 wt% ± 0.88 wt% (n=5);
- Cu concentrations average 33.46 wt% ± 1.50 wt% (n=5).

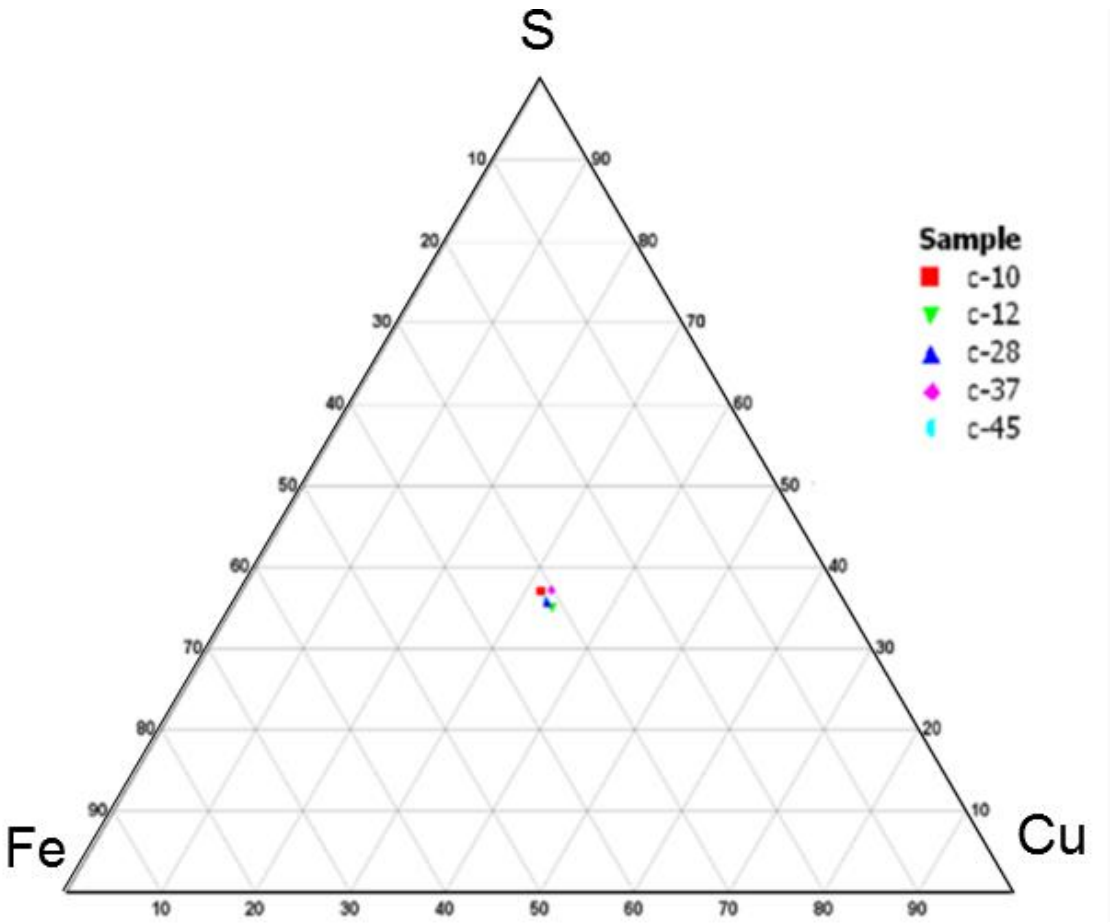


Figure 6.3. - Ternary S+Fe+Cu plot of the chalcopyrite microanalyses from SEM EDS. Individual plots per crystal result.

6.2. Oxides

6.2.1. Magnetite

Magnetite is the main iron oxide in the study area and is present in various forms and shapes. Magnetite crystals are often associated with alteration of olivine and/or pyrrhotite, pentlandite, chromite and to a lesser extent chalcopyrite (Figure 6.4 and 6.5). Magnetite has a range of Fe content from 66.08 to 71.58 wt% (with an average of 69.43 wt% ± 2.57 and n=4); O contents range from 28.23 to 31.62 wt% (with an average of 31.62 wt% ±2.29 and n=4).

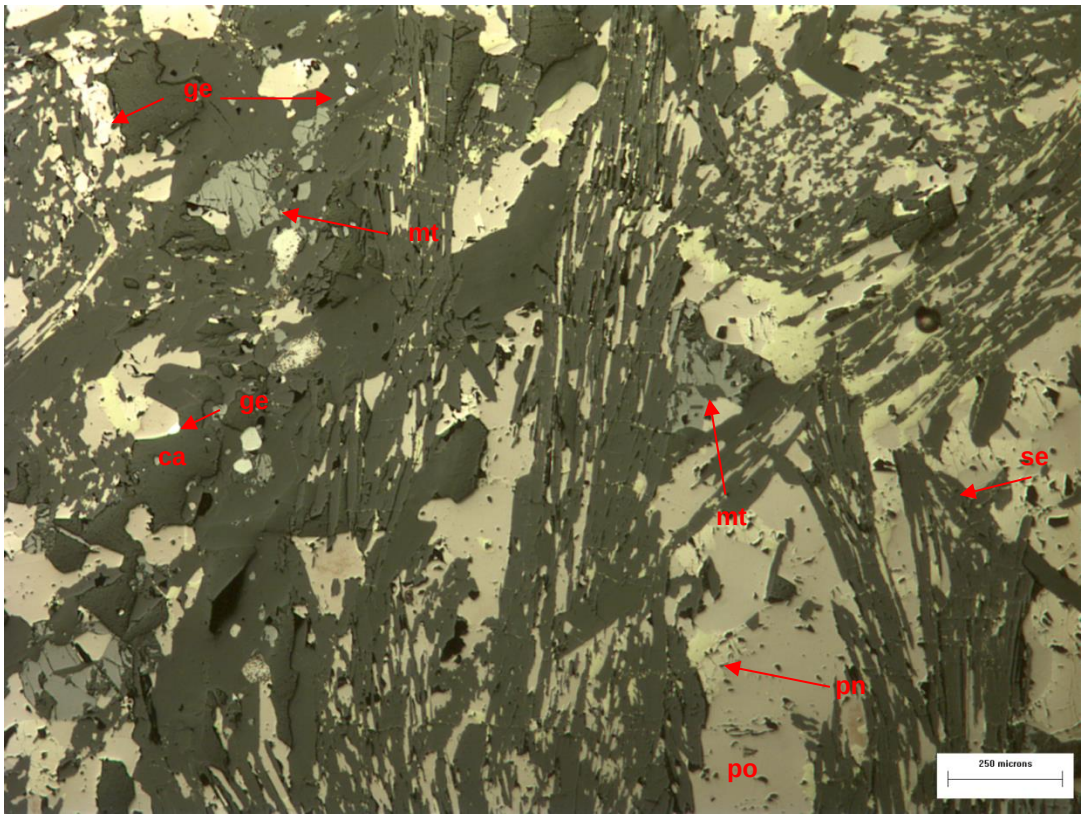


Figure 6.4. - Photomicrograph of magnetite (mt) in serpentine (se) and carbonate (ca) rich rock. gersdorffite (ge) crystals. Disseminated and matrix pyrrhotite (po) with pentlandite inclusions (pn) and disseminated gersdorffite, sample C-29, RL. PP.

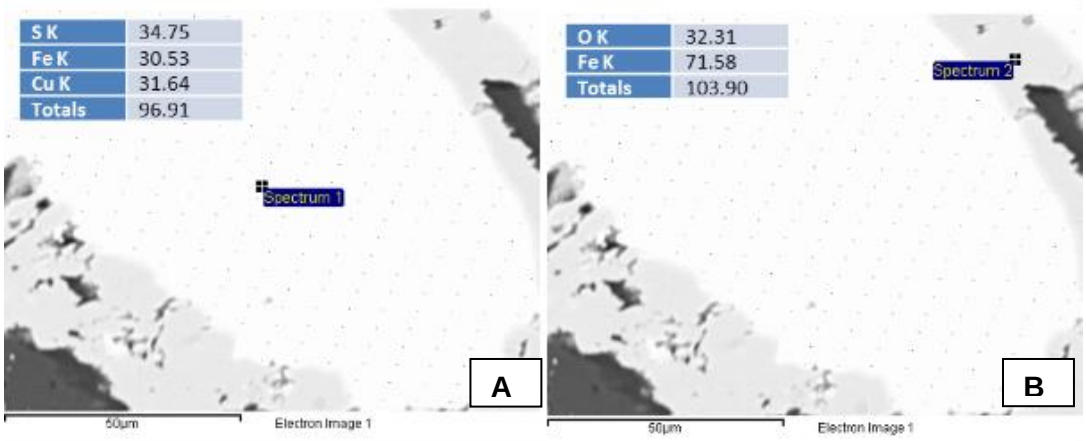


Figure 6.5. - SEM BSI showing chalcopyrite crystals (A), spectrum 1 element proportions, with magnetite rim (B), spectrum 2 element proportion, sample C-45.

6.2.2. Cr-Spinel

Cr-spinel was detected mostly as small clusters of ferri-chromite grains. No pristine euhedral igneous chromite without magnetite alteration was identified. All chromite features magnetite rims or magnetite along fractures. Chromite occurs as disseminated grains in some of the massive sulphide and matrix samples, where they can be blocky and euhedral or, less commonly, partially skeletal. Advanced replacement of chromite by zoned chromian magnetite and then magnetite (see on Figure 6.6) is found in most of the samples, with some examples (sample C18, Figure 6.7), representing approximately 10 % of the mode; chromite cores have almost completely disappeared in this sample.

Some chromian magnetite rims contain sulphide and sulpharsenide inclusions (Figure 6.7).

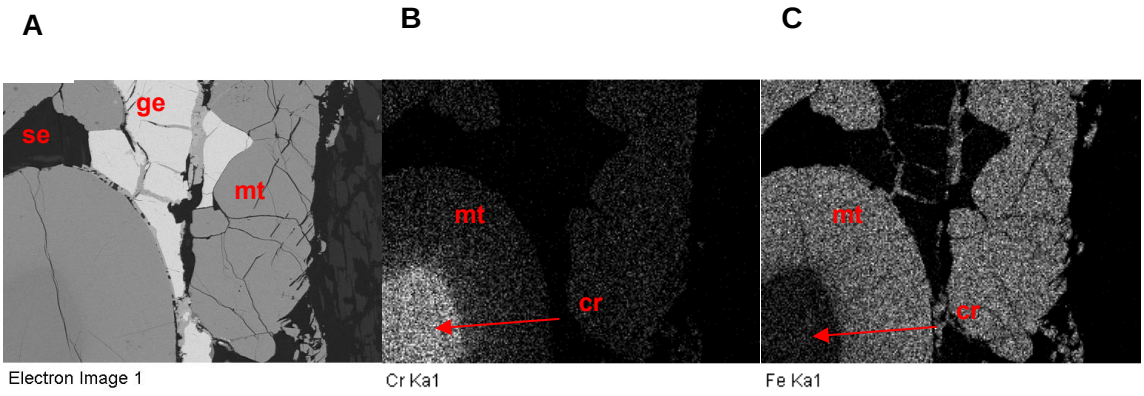


Figure 6.6. - SEM BSI with EDS scan mapping showing chromite (cr) core and magnetite rim (mt) (A). Note the Cr inside the core of the mineral (B) and Fe replacement (C). Other minerals are: gersdorffite (ge), magnetite (mt) and serpentine (se). Sample C- 35.

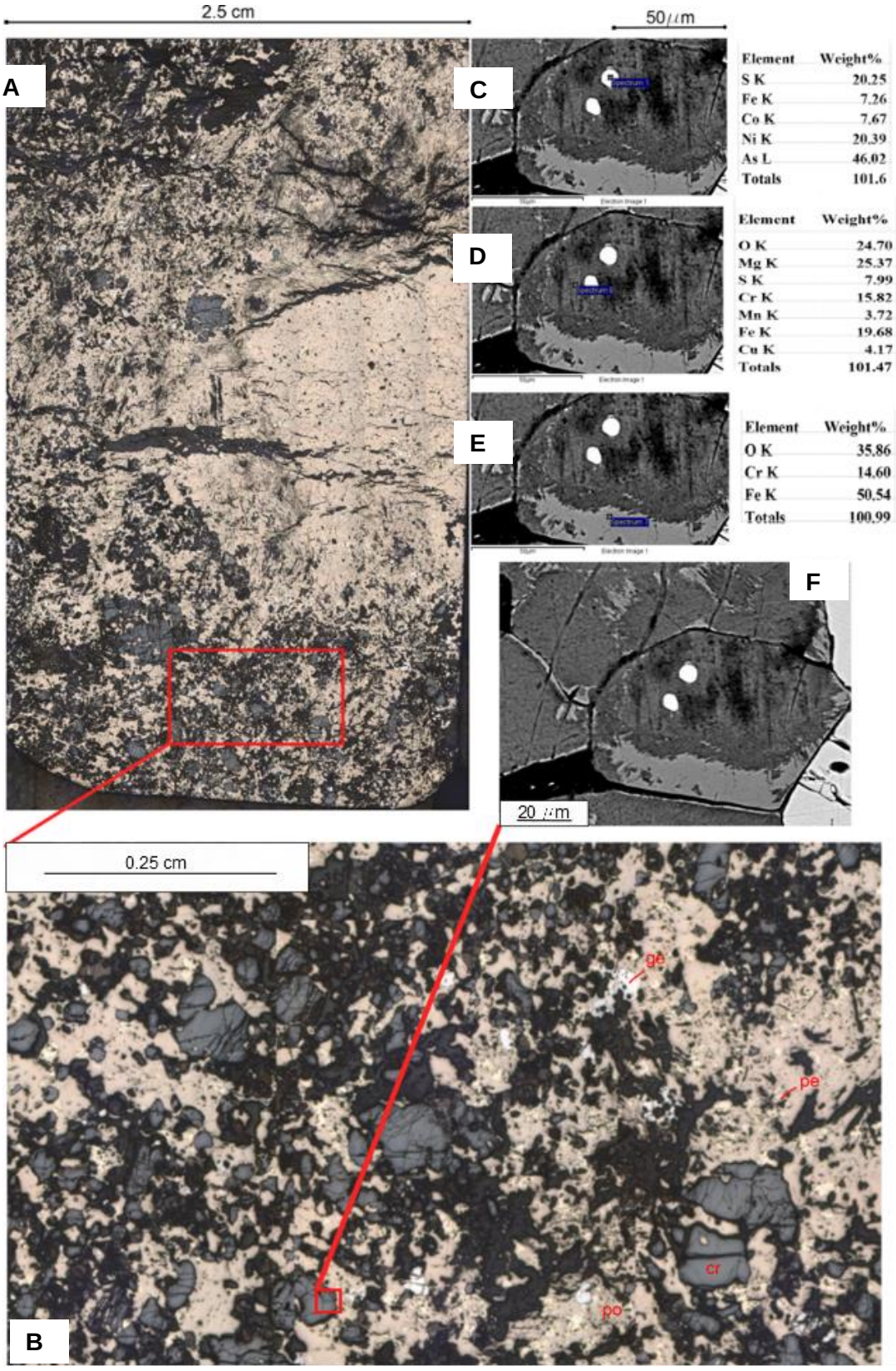


Figure 6.7. - RL.XP photomicrograph of the entire thin section of sample C-18 (A), showing massive sulphide pyrrhotite (po) matrix with pentlandite (pn), the matrix is also rich in chromite/magnetite and gersdorffite with minor gangue minerals; (B) Detail of A; (C) secondary gersdorffite inclusion; (D) chromite with gersdorffite inclusion; (E) chromite; (F) detail of B showing chromian magnetite with small round gersdorffite inclusions. Detailed pictures are SEM BSI with its respective spectrum composition.

Chromite composition in komatiites can be influenced by metamorphic processes, particularly those occurring above 500°C (Barnes, 2000). Peak metamorphism at Perseverance deposit has been documented as ranging from 535°C to 560°C (Gole et al, 1987), so chromite alteration is possible. Metamorphosed chromite is substantially more iron rich than its igneous precursor, as a result of Mg–Fe exchange with silicates and carbonates (Barnes, 2000). This pattern was noted by Barnes (2000), during a study of chromite samples from the Perseverance deposit. Figure 6.8 shows the Fe^{3+},Cr, Al ternary diagram of the chromite microanalyses from the study area and compares them to the results for the “rims” and the “cores” of chromite samples from Barnes (2000).

Chromite metamorphosed to amphibolite facies is enriched in Zn and/or Fe and depleted in Ni, when compared to chromite documented from lower metamorphic grades (Barnes, 2000). It is typically extensively replaced by magnetite (resulting in ferri-chromites), and its composition on the inner chromite–magnetite boundary is an indicator of metamorphic grade (Barnes, 2000). Significant Al is lost from chromite cores above 550°C as a result of equilibration with fluids in equilibrium with chlorite. Cobalt and manganese behave similarly to each other (Barnes, 2000). Metamorphism in the 550–600°C range marks the limiting condition where igneous compositions are substantially modified by equilibration between chromite cores, magnetite rims, and surrounding silicates such as chlorite (Barnes, 2000). This trend of Fe enrichment and depletion in Ni is noted in all chromite and chromian magnetite grains presented in this study. No chromite compositions consistent with primary magmatic values, according to the criteria described by Barnes, 2000, were found inside the Cr cores analysed for this study.

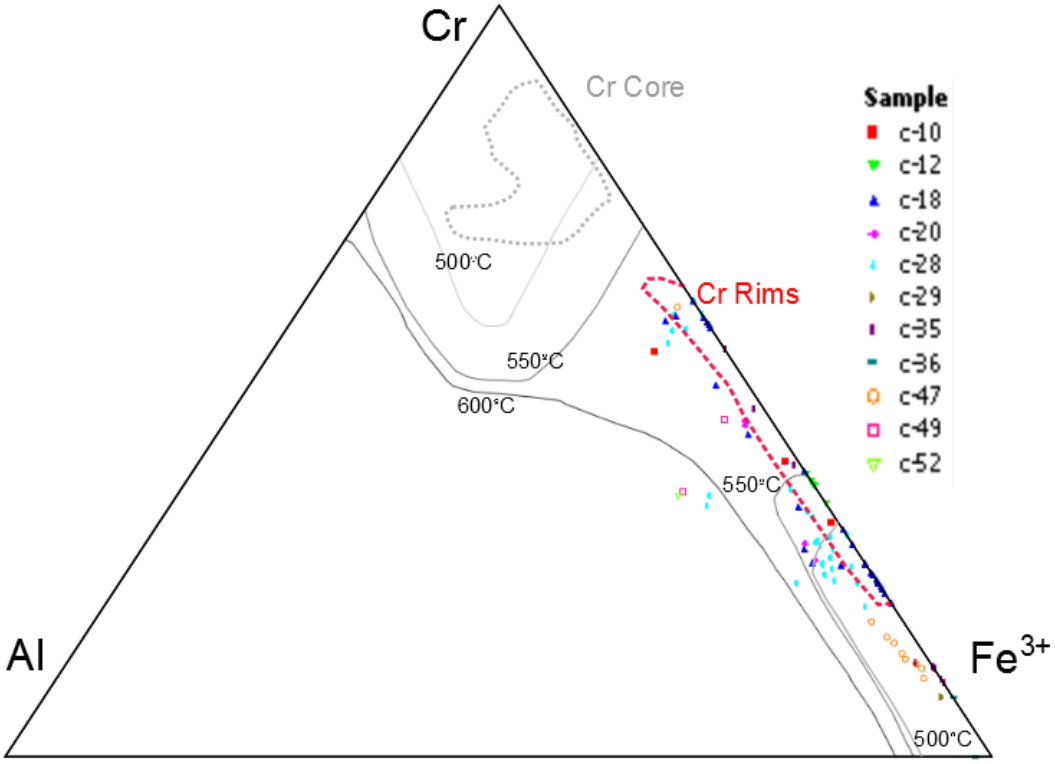


Figure 6.8. - Ternary Cr+Al+Fe^{3+} diagram of chromite and chromian magnetite grains microanalyses by SEM EDS. Geothermometric lines are based on Sack and Ghiorso (1991) with spinel stability limits for chromite and magnetite (calculated at equilibrium with olivine of composition Fo90) from Barnes (2000). Contour limits for Cr Core and Cr Rim from data for spinel analyses from across-grain traverses from previous work at Perseverance deposit (Barnes, 2000) and as noted no fresh Cr core samples were obtained in this study. Such samples would represent the magmatic phase described by Barnes, (2000).

6.3. Sulpharsenides

All sulpharsenide microanalyses (from a total of 335 grain analyses) were plotted in the ternary system NiAsS - CoAsS – FeAsS (Figure 6.9; after Klemm (1965)). There are two groups; Co-rich analyses, and Ni-rich analyses, which is consistent with the petrological identification of cobaltite and gersdorffite respectively. No arsenopyrite crystals were identified in the study area and the Fe shown in Figure 6.10 represents the total Fe in cobaltite and gersdorffite grains. The position of the points relative to the contours indicates the expected minimum temperature of crystallisation.

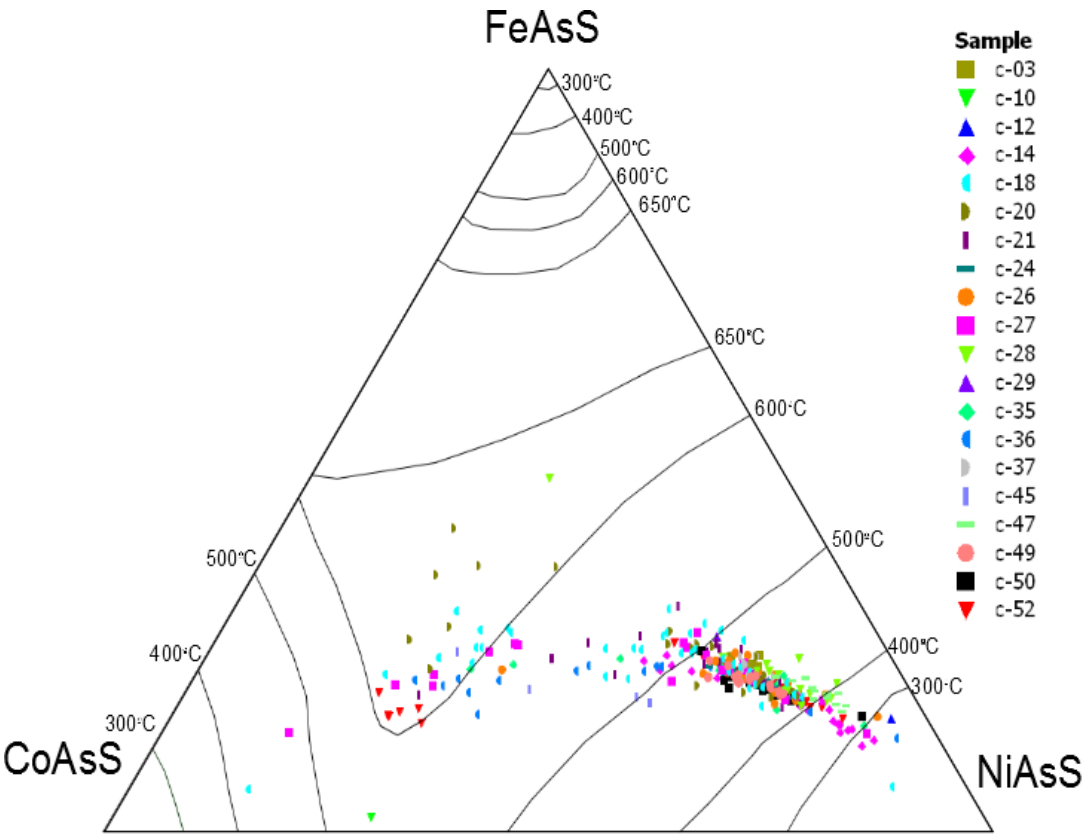


Figure 6.9. - Ternary plot of the analysed individual sulpharsenide grains relative to the solvus in the condensed system FeAsS-CoAsS-NiAsS at 300ºC, 400ºC, 500ºC, 600ºC and 650ºC. Solvi from Klemm (1965). Sample legend is located to the right.

6.3.1 Gersdorffite

This mineral is represented by a wide range of Ni and Co concentrations and less variable contents of As, S and Fe. The ratio of Co and Fe to Ni in gersdorffite is approximately Fe/Ni = 0.29 and S to As is 0.47 (Table 6.1). Gersdorffite is found as small crystals or as round grains preserved in massive pyrrhotite, or inside pentlandite and ferri-chromite (present in samples C-14, C-18, C-20, C-21, C-24, C-27, C-28, C-35, C-36, C-45 and C-52). The smaller gersdorffite grains (illustrated on Figure 6.11) are generally the richest in cobalt and have an inferred minimum temperature above 500ºC, according to solvi in the condensed system FeAsS-CoAsS after Klemm (1965).

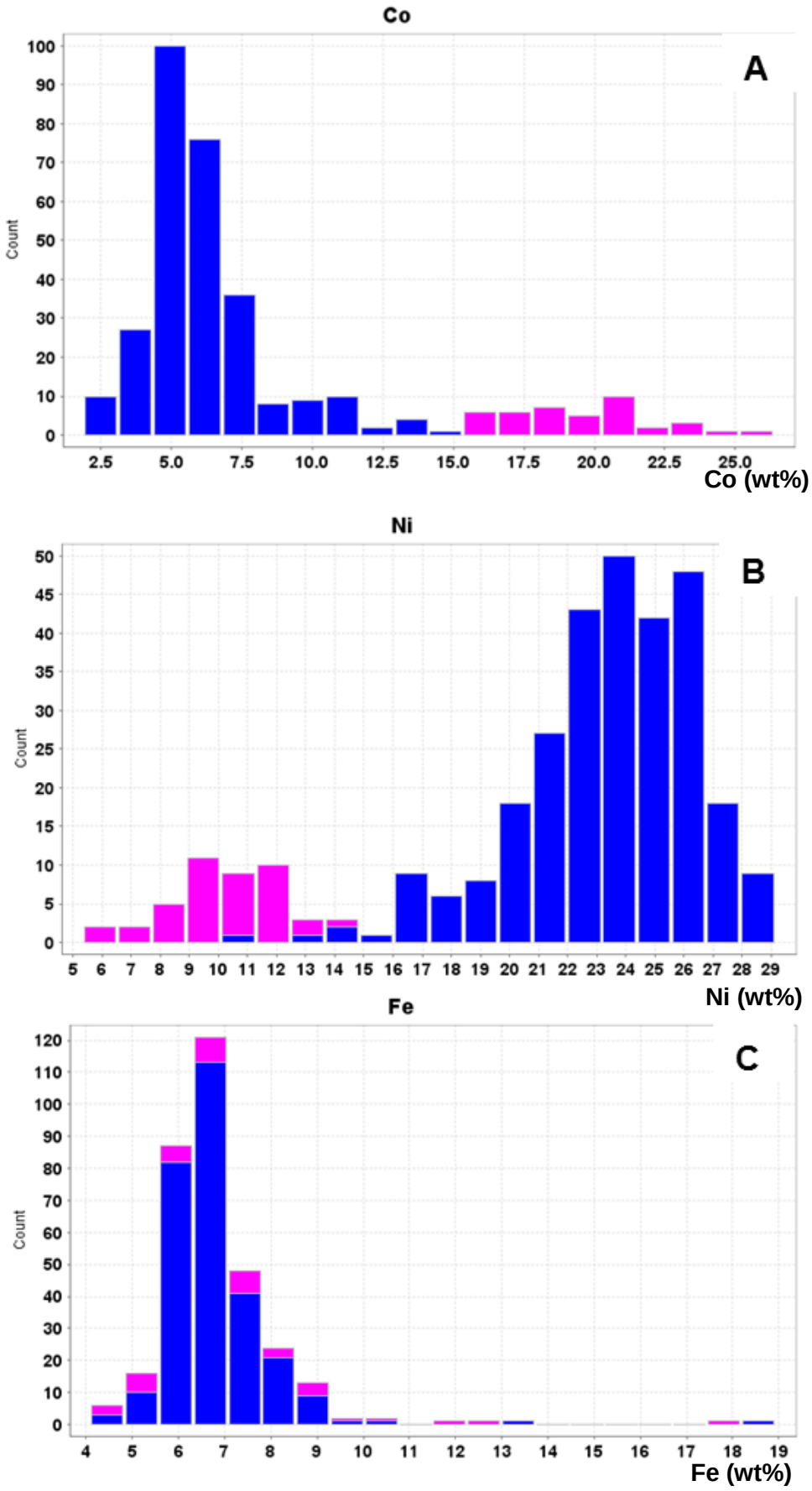


Figure 6.10 - Histograms of Co (A), Ni (B) and Fe (C) of the 324 grain analyses from sulpharsenides analysed on SEM EDS. Blue bars represent the gersdorffite population and pink the cobaltite population. Note an overlap of the Fe samples, confirming a relatively constant amount of Fe in all samples.

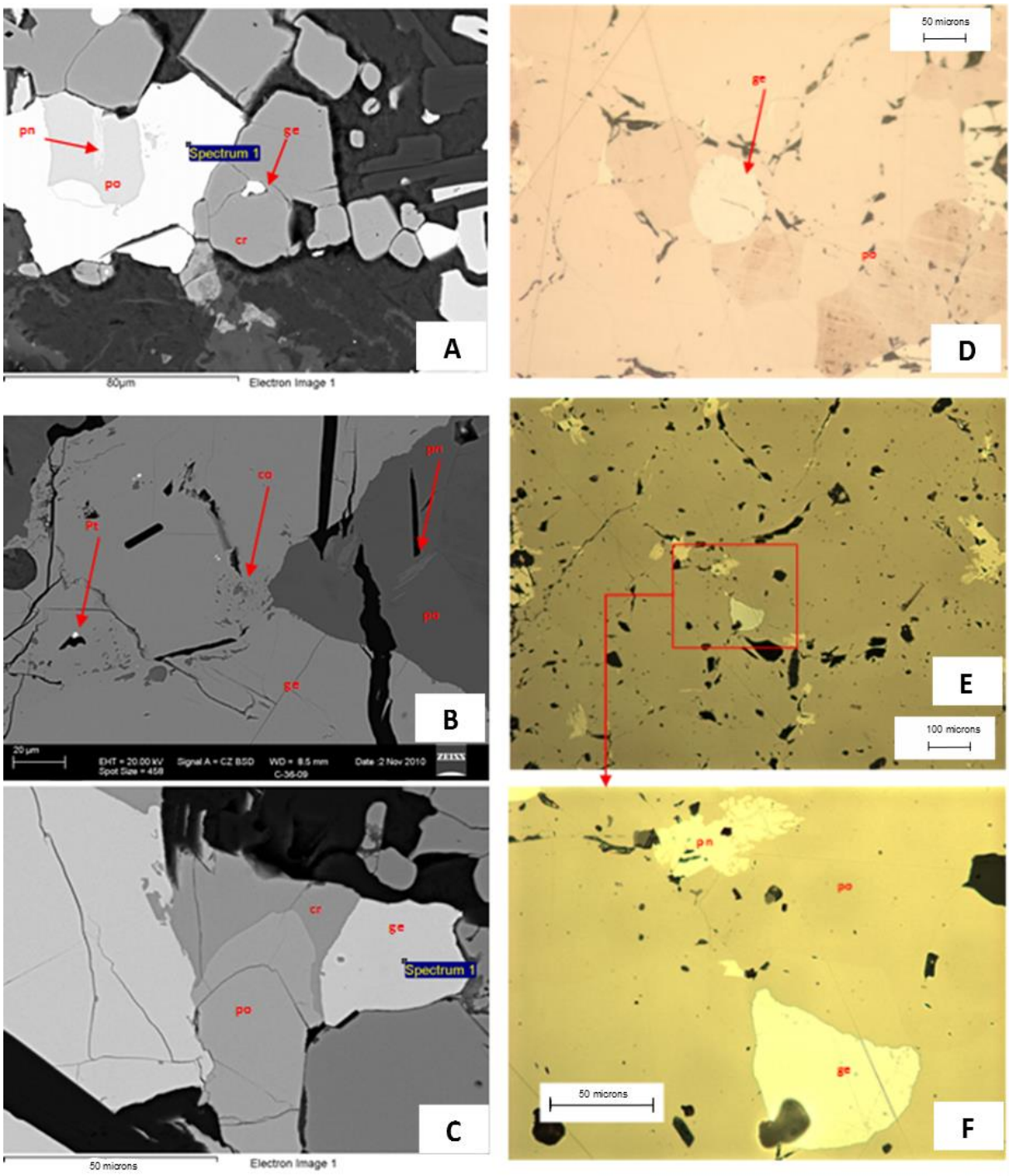


Figure 6.11. - SEM backscattered images of high temperature facies gersdorffite with higher amounts of Co and Fe: (A) sample C-52 - gersdorffite intergrown with chromite (cr); (B) sample C-36: gersdorffite with minor alteration to cobaltite (co), and a small inclusion of Pt; (C) sample C-50: gersdorffite intergrown with chromite (cr).

Photomicrographs of high temperature gersdorffite (ge): (D) sample C-09 – reflected light on polished section) with small droplet of gersdorffite in massive pyrrhotite (po); (E and F) sample C-18 reflected light on polished thin section with gersdorffite (ge) in massive pyrrhotite (po) and pentlandite with flame like texture exsolution.

Table 6.1. - Summary of Ni, As, S, Fe and Co concentrations of gersdorffite.

	Ni (wt%)	As (wt%)	S (wt%)	Fe (wt%)	Co (wt%)
Number of analysis	295	295	295	295	295
Minimum	11.17	34.61	18.39	4.64	1.89
Maximum	29.13	48.52	24.36	18.92	14.77
Mean	23.44	43.23	20.53	6.78	6.04
Standard deviation	3.01	1.36	0.73	1.19	2.12

The majority of the gersdorffite grains analysed are Ni-rich. The morphology of these Ni-rich grains varies, with textures that include small and scattered grains in the gangue matrix, small grains filling small cracks in ore minerals and coarse aggregates replacing sulphide phases; the latter texture is most common along shear zones. The crystals commonly form euhedral grains of small size (<20 µm) and can also be present scattered within the groundmasses in the carbonate-rich and tremolite-rich zones. Some gersdorffite occur within pentlandite. There are some idioblastic grains, generally coarse, which form along aggregates of altered olivine and/or tremolite + carbonates (Figure 6.12). The Ni-rich gersdorffite variety is interpreted to have an expected minimum temperature of crystallisation above 250 ºC, suggesting a lower temperature than the cobalt-rich gersdorffite types.

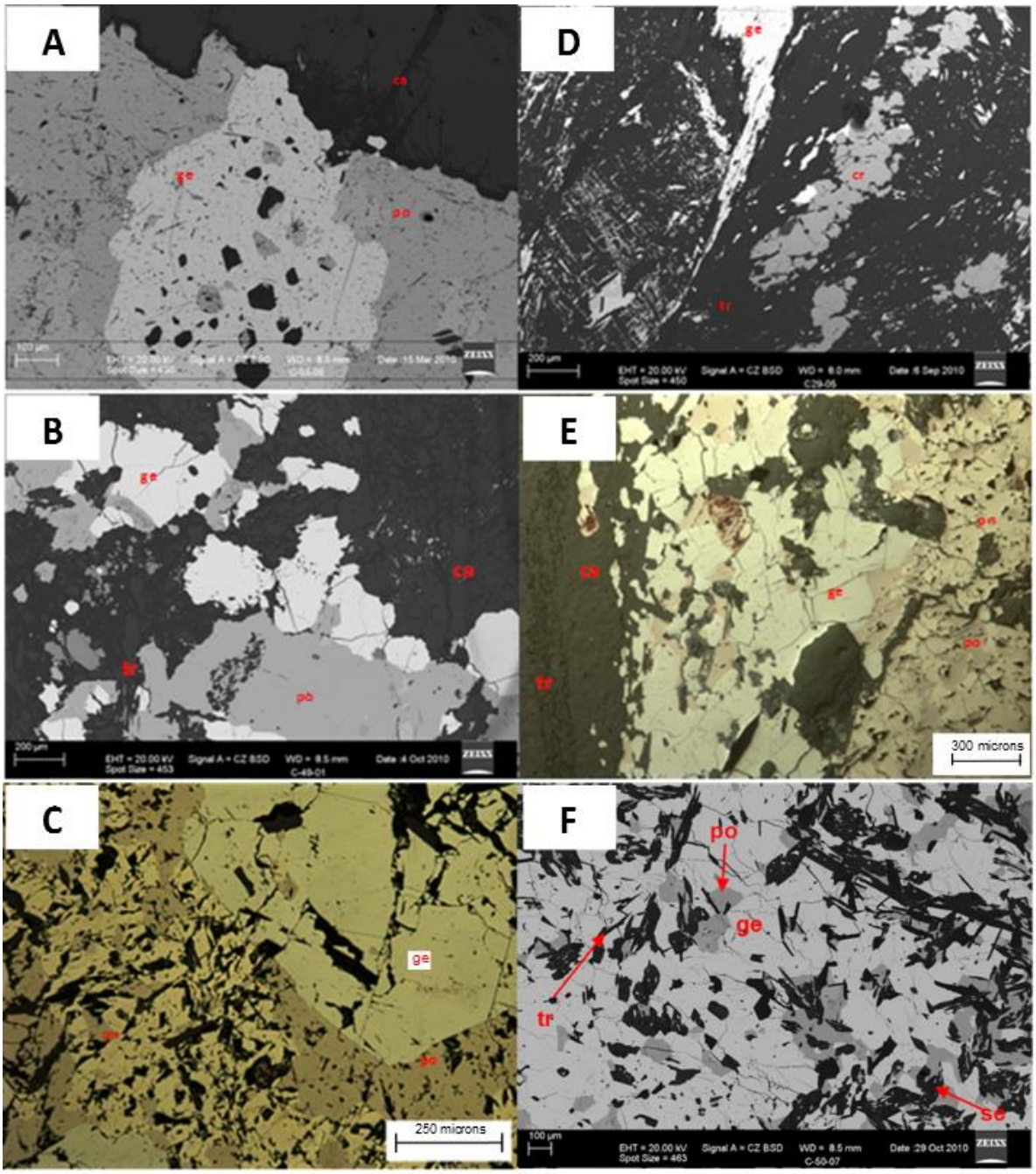


Figure 6.12. - SEM BSI (A and B) and one photomicrograph (C) of different sizes and forms of occurrence of Ni rich gersdorffite (ge). Grains are small to coarse and mostly found in re-crystallised veins associated with carbonates (ca) and amphiboles (tremolites - tr) in the highly altered zones: (A) sample C-03: gersdorffite with inclusions of minerals that have been substituted (pyrrhotite, pentlandite and serpentine), (B) sample C-49; gersdorffite intergrown with later mineral assemblage (tremolite(tr)+carbonate(ca)); (C) sample C-03 RL.PP. coarse recrystallised and cubic euhedral gersdorffite (ge) and recrystallised pentlandite (pn).

SEM BSI (D and F) and one photomicrograph (E) of Ni rich gersdorffite (ge): (D) sample C-29: secondary gersdorffite crystallised along border of silicate, tremolite(tr), along a shear zone; (E) sample C-24: RL.PP. (100µm scale) gersdorffite (ge) intergrown with later tremolite(tr)+carbonate(ca); (F) sample C-50: secondary gersdorffite (ge) vein with inclusions of pyrrhotite (po) and tremolite (tr) and serpentine (se).

6.3.2. Cobaltite

Cobaltite is rarer than gersdorffite and generally occurs as small crystals, 10 to 150 µm in diameter (present in samples C-10, C-18, C-20, C-21, C-26, C-27, C-35, C-36, C-45 and C-52). It is often found in association with gersdorffite and sometimes rims the gersdorffite crystals (Figure 6.14). Cobaltite can also feature euhedral grains and in some cases it forms irregular cobaltite – gersdorffite intergrowths. Other textural types of cobaltite can be found as inclusions in a pyrrhotite matrix (Figure 6.13). One gold grain was found in association with cobaltite (Figure A4.1 in Appendix 4). Element ratios calculated from the microanalyses of cobaltite are approximately Co:Ni = 1.95; Fe:Ni = 0.74; and S:As = 0.51.

Table 6.2. Summary of Ni, As, S, Fe and Co concentrations of cobaltite.

	Ni (wt%)	As (wt%)	S (wt%)	Fe (wt%)	Co (wt%)
Number of analyses	40	40	40	40	40
Minimum	5.32	30.99	17.7	4.09	15.82
Maximum	13.68	46.8	26.52	17.52	26.35
Mean	10.03	42.02	21.29	7.38	19.53
Standard deviation	1.95	2.66	1.34	2.5	2.56

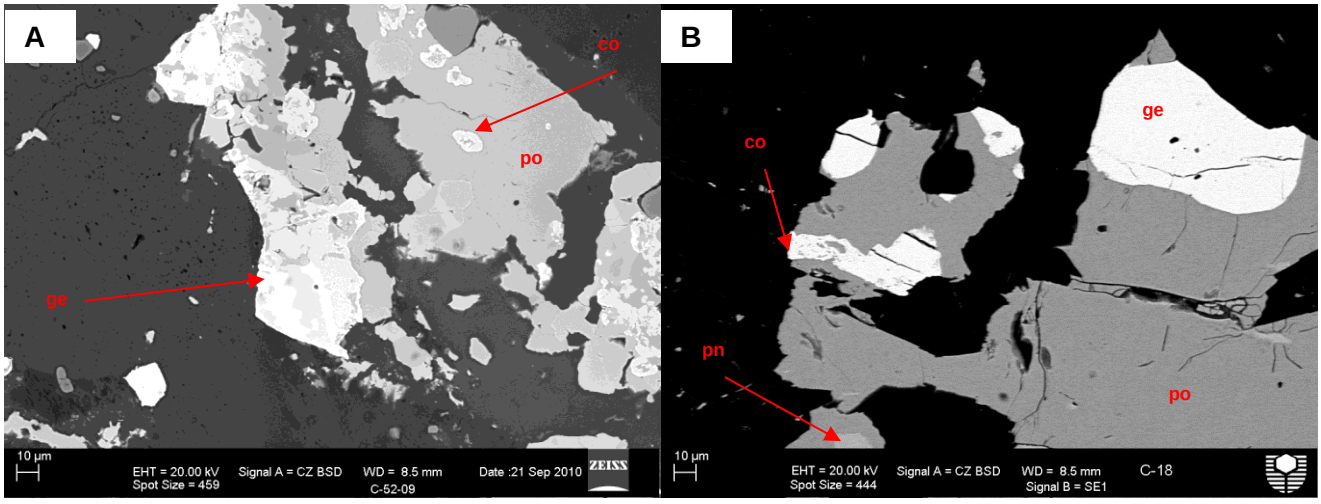


Figure 6.13 – SEM BSI of cobaltite: (A) sample C-52 cobaltite as inclusions in pyrrhotite (po); (B) sample C-20 cobaltite (co) intergrown with pyrrhotite (po),which also contains some gersdorffite (ge) crystals

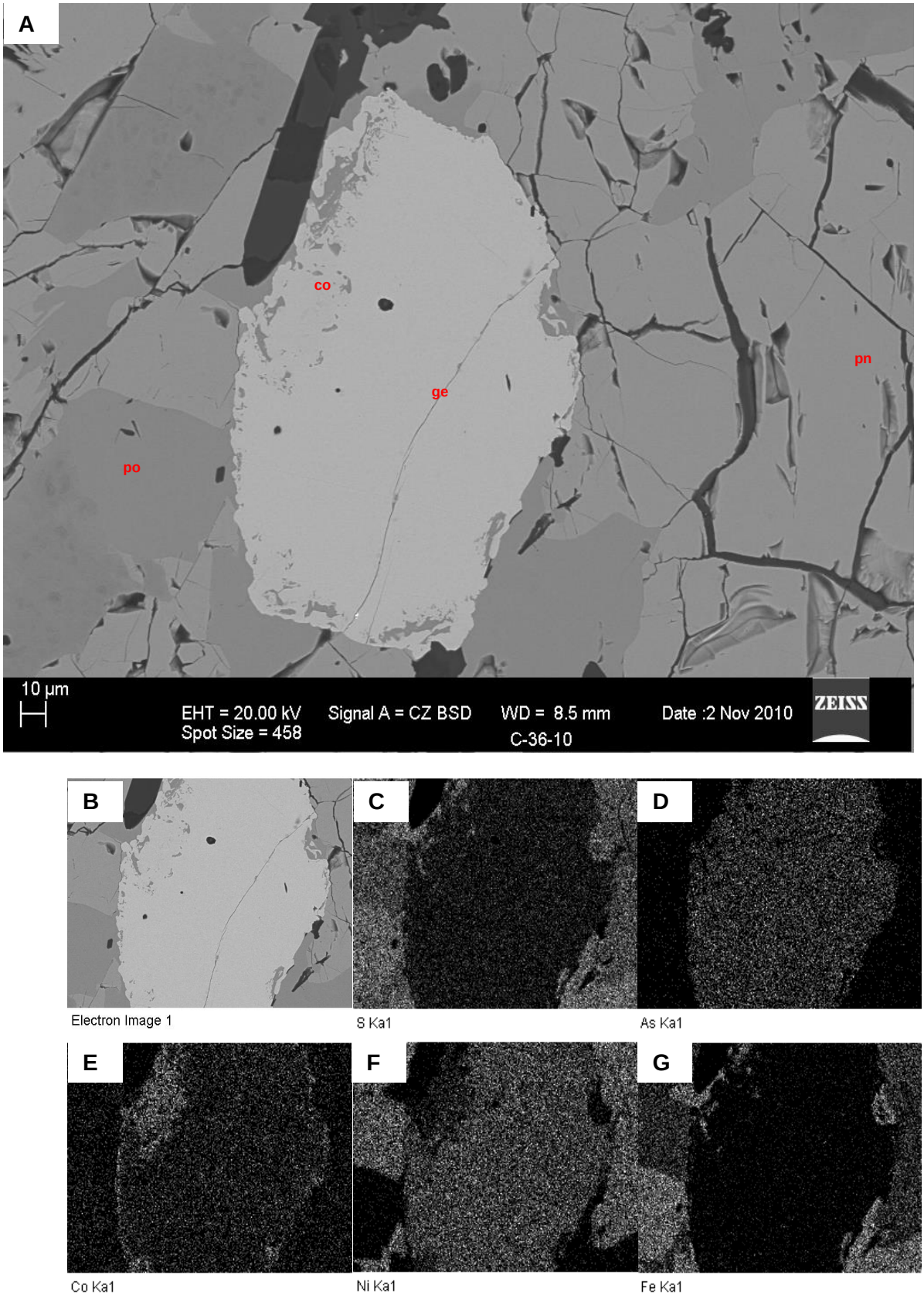


Figure 6.14. - SEM BSI (A) sample C-36 of rounded droplet of gersdorffite (ge) with an rim of cobaltite (co) in massive sulphide with pyrrhotite (po) and pentlandite (pn). EDS scan mapping global image (B), element mapping S (C), As (D), Co (E), Ni (F) Fe (G) showing gersdorffite with the outer zoning of cobaltite (note rim of Co around grain).

6.3.3. Interpretation of temperature of mineral equilibration of sulpharsenides

Compositions of the crystals of gersdorffite associated with, or as inclusions inside ferri-chromite, were individually plotted together with the compositions of their host or adjacent ferri-chromite (Figure 6.15). The ferri-chromite grains contain inclusions of arsenic-bearing minerals and have high amounts of Fe and other elements, such as S, Mg, Mn and minor amounts of Cu and Zn,, indicating that the crystals have been affected by alteration and do not exhibit primary magmatic composition. Based on Figure 6.15, the ferri-chromites and sulpharsenides equilibrated at minimum temperatures ranging from approximately 450 to 570 ºC. The results are based on the ternary diagram of sulpharsenides (Figure 6.15A) and the ternary Cr-Al-Fe^{3+} diagram (Figure 6.15F). Thus, the sulpharsenides and ferri-chromite recorded temperatures near or below the peak of metamorphism, as determined by Gole et al (1987) and described on Chapter 2, Section 2.2.4.

Miscibility between arsenopyrite and cobaltite and between arsenopyrite and gersdorffite is more limited, particularly at low temperatures, because of differences in the crystal structures of the pseudo orthorhombic system for arsenopyrite and pseudo cubic for cobaltite and gersdorffite (Beziat et al, 1996).
Most of the sulpharsenides analysed in the present study recorded varying minimum temperatures, from ~280 to 610ºC (Figure 6.9). Minimum temperatures for most of the gersdorffite associated with cobaltite rims fall between 400 and 550 ºC whereas cobaltite on the rims records significantly higher minimum equilibrium temperatures, 550 to 610 ºC (Figure 6.16). If the sulpharsenides equilibrated in a closed system on the scale of the sulpharsenide grains then co-existing cobaltite and gersdorffite could have ex-solved from an original gersdorffite grain formed at higher temperatures than those recorded by present day compositions.

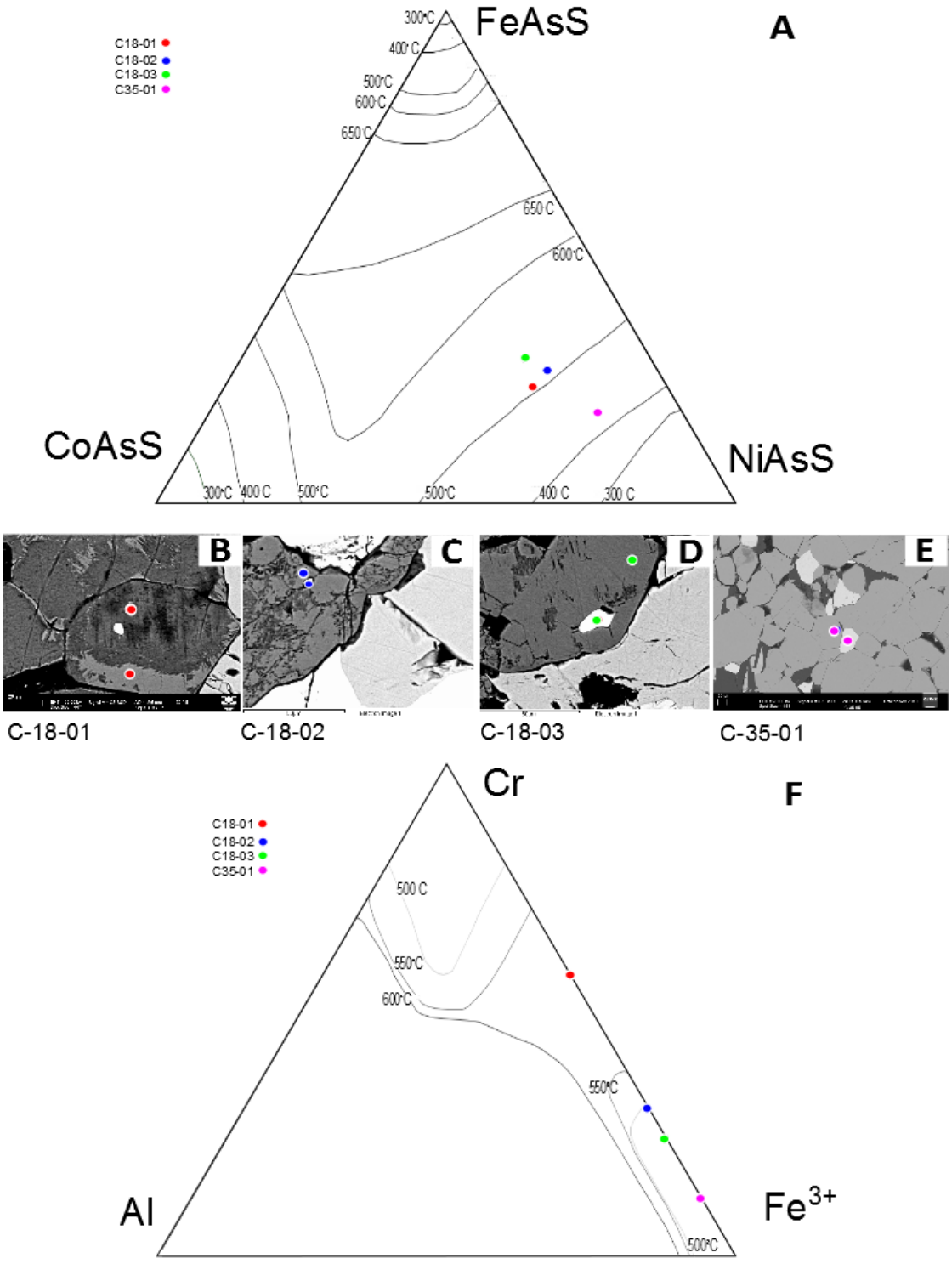


Figure 6.15. - Ternary FeAsS-CoAsS-NiAsS diagram (A) of the analysed sulpharsenides co-existing with ferrichromites, including solvi in the condensed system from Klemm (1965). Individual symbols refer to gersdorffite present as inclusions or associated with ferri-chromite. (B to E) SEM BSI from individual crystals of gersdorffite inclusions or associated with ferri-chromite, sample C-18 (B, C and D) and C-35 (F) Ternary Cr-Al-Fe^{3+} diagram showing ferri-chromites associated with gersdorffite. Geothermometric contours based on Sack and Ghiorso (1991) spinel stability (F).

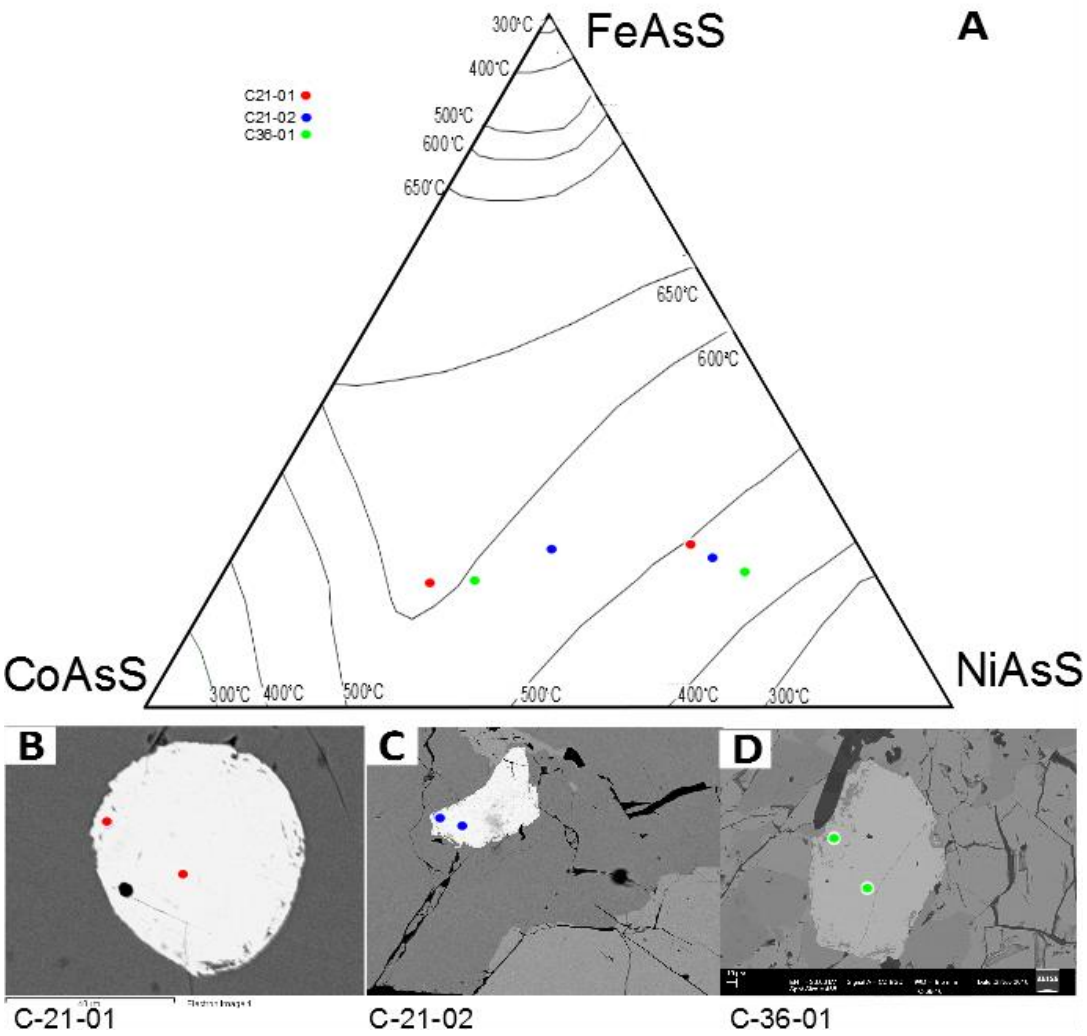
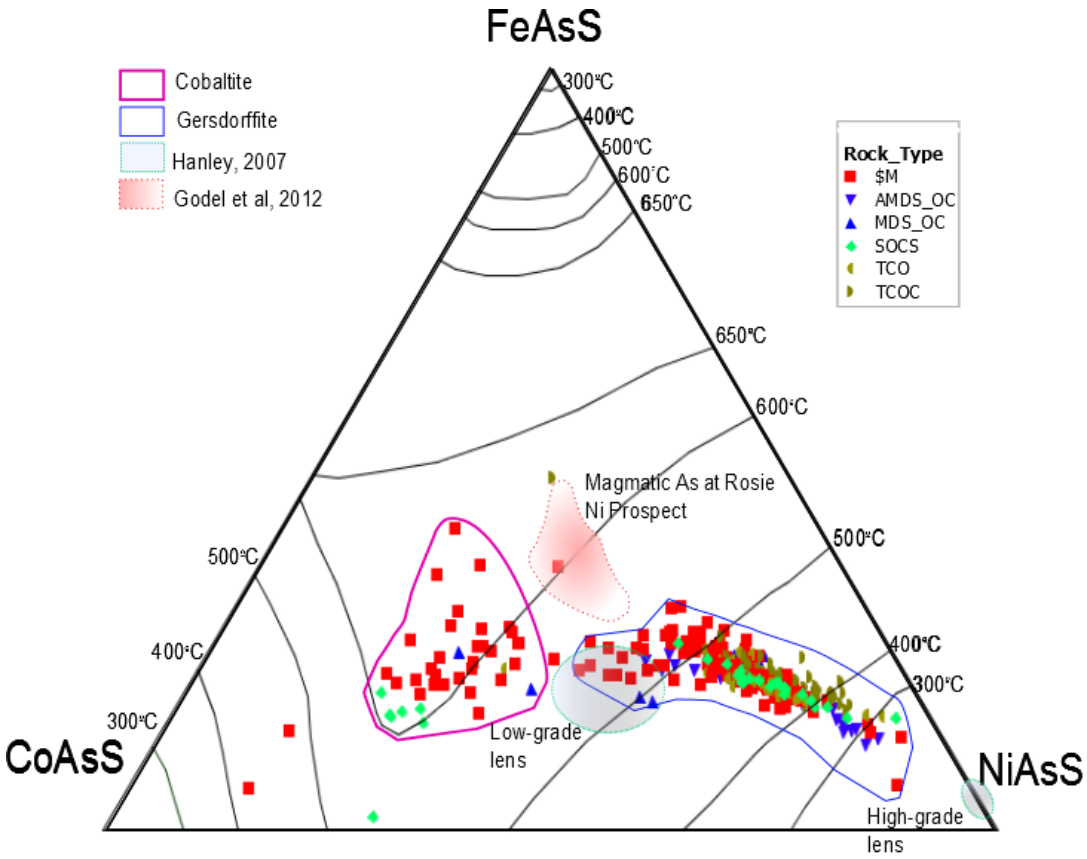


Figure 6.16. - (A) Ternary FeAsS-CoAsS-NiAsS plot of the analysed sulpharsenides showing solvi in the condensed system from Klemm (1965). Individual plots for grains of gersdorffite with cobaltite rims. (B to D) SEM BSI from individual crystal analyses of gersdorffite (right side of the ternary plot) with cobaltite rims (left side of the ternary plot). Sample C-21 (B and C) and C-36 (D).

Cobaltite samples have in general less variable Co and Ni concentrations than gersdorffite, so the data distribution is quite tightly clustered when plotted in the condensed system FeAsS-CoAsS-NiAsS of Klemm (1969), Figure 6.17. The interpretation of cobaltite data suggests that most of the minerals analysed crystallised at temperatures higher than 500 ºC. Gersdorffite on the other hand, contains more variable Co and Ni concentrations and the data distribution follows a trend on the ternary FeAsS-CoAsS-NiAsS diagram of Klemm (1969), Figure 6.17. The interpretation of gersdorffite data suggests that grains crystallised, or re-equilibrated at, a wide range of minimum temperatures, from approximately 550 ºC to 250 ºC.

Sulpharsenides of magmatic origin have been described at the nearby Rosie Nickel Prospect (Godel et al, 2012) and other regions over the world that include Dundonald Beach South in the Abitibi Sub province, Canada (Hanley, 2007) and the compositions of samples from these localities are included on Figure 6.17 for comparison with sulpharsenides from the Perseverance deposit.



Rock Type	Abbreviation	Samples
Massive sulphide	$M	C-18, C-20, C-21, C-24, C-27, C-35, C-36, C-49
Altered matrix and disseminated sulphide olivine-cumulate rock with carbonate rich zones	AMDS_OC	C-14
Matrix and disseminated sulphide olivine-cumulate	MDS_OC	C-03, C-45
Serpentinised olivine-cumulate sulphide rock	SOCS	C-10, C-12, C-52
Tremolite-chlorite-olivine rocks	TCO	C-26, C-50
Tremolite-chlorite-olivine rocks with carbonate rich zones	TCOC	C-28, C-29, C-37, C-47

Figure 6.17 - CoAsS-FeAsS-NiAsS ternary diagram (mol %) showing the major elemental composition of sulpharsenides from the Perseverance deposit. The isotherms represent the upper limits of immiscibility (two phase fields) at various temperatures (after Klemm, 1965). Sulpharsenide compositions Rosie Ni Prospect (Godel et al, 2012) and Dundonald Beach South (Hanley, 2007) are plotted for comparison. Sample legend is located above and the areas of concentration of the two sample types, cobaltite (pink polygon) and gersdorffite (blue polygon).

6.4. Mineral proportions and nickel tenor at the sample scale

For massive sulphides and potentially heavy disseminated sulphide ore, whole rock Ni-S ratios can be used as a proxy for nickel tenor (Ni wt% in a 100 wt% sulphide) due to the linear relationship between the two measures (Chambers, 2008 and Seat et al, 2004). However, this linear relationship is not applicable if there are high amounts of As in the system, or if a large component of the Ni is hosted by silicate minerals.

Figure 6.18 is a plot showing the whole-rock Ni concentrations as a function of S concentrations for all the samples considered in this study, where the size of the dot increases with increasing As concentration. Two trends are evident and are related to the arsenic concentrations within the samples. Samples of lower arsenic content (typically < 1000 ppm As) follow a linear trend (Figure 6.19) with an intercept close to 0 wt% Ni (with intercept at 0.17 wt% Ni) suggesting that all Ni is hosted by sulphide-bearing minerals, despite Ni being generally common in olivine crystals, but at low levels compared to the level in pentlandite. Nickel-poor olivine was observed by Barnes et al (2011) at Perseverance. These authors suggested that Ni concentrations in olivine present prior to the first episode of serpentinisation at Perseverance deposit are depleted by a factor of two or more relative to model concentrations for olivine produced by sulphide-free fractionation of komatiitic magma. In contrast, the samples with higher As concentrations form another linear trend toward higher Ni concentrations for any given S concentration. The higher Ni concentration in the upper trend is interpreted to reflect variable proportions of gersdorffite and cobaltite in addition to the As-free sulphide minerals.

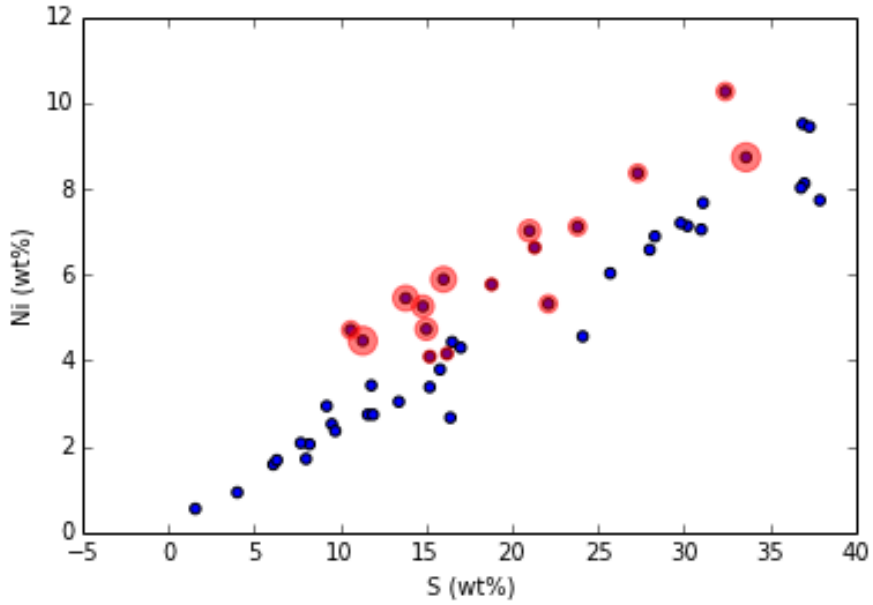


Figure 6.18. - Ni-S concentrations of massive sulphide and altered and non-altered olivine-sulphide-cumulates and tremolite-chlorite-olivine rocks. Blue dots are samples with <1000 ppm As. The size of the red bubbles represent the As content of each sample. The smallest red dot represents samples with 1,000 to 10,000 ppm As and dots with a lighter coloured halo represent samples with more than 10,000 ppm As. Samples with more As tend to plot above the trend of samples with low As.

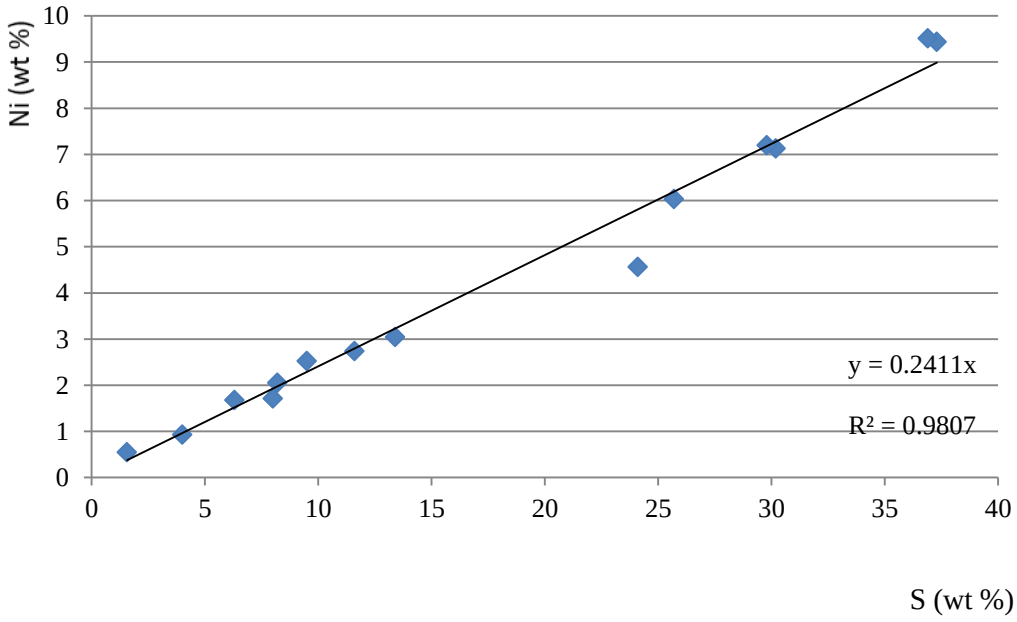


Figure 6.19. - Ni-S concentrations of massive sulphides, altered and non-altered olivine-cumulate sulphide rock and tremolite-chlorite schist of samples with less than 1,000ppm As. The line describes the dominant Ni-S trend which intersects the y axis within error of zero.

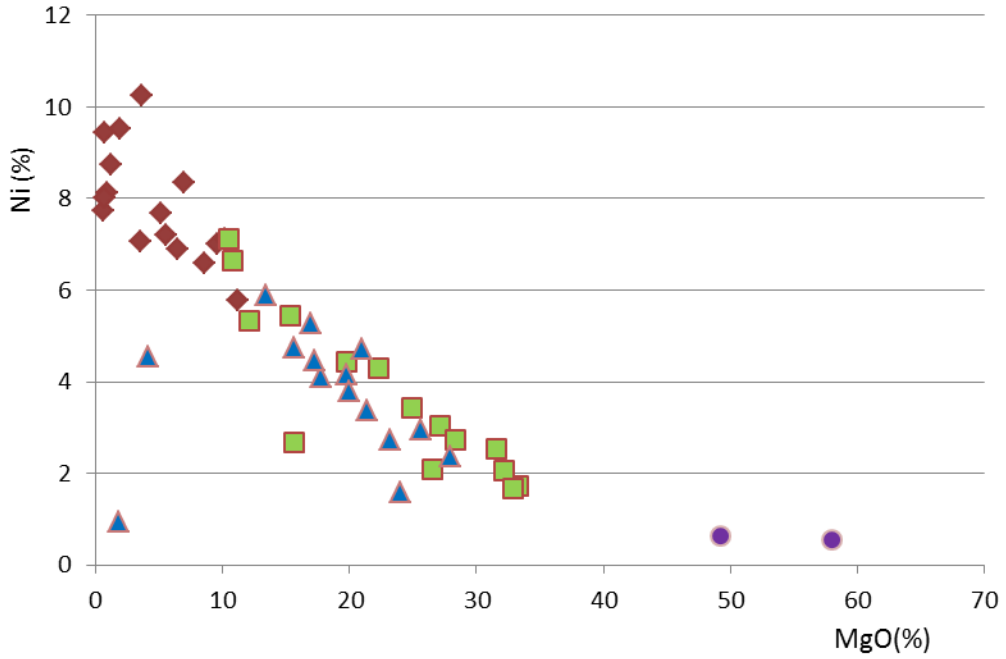


Figure 6.20. - MgO-Ni data of massive sulphides shown in red (diamond shape), olivine-adcumulate in purple (circle shape), olivine-cumulate sulphide rock in blue (triangle shape) and tremolite-chlorite schist in green (square shape).

Ore mineral proportions were calculated using a constrained least squares method (Godel, personal communication) using whole-rock and mineral chemistry and by considering that:

- All the Cu is hosted by chalcopyrite as observed during the mineralogical analyses;
- Ni is hosted by pentlandite, gersdorffite, cobaltite and to a lesser extent pyrrhotite with insignificant Ni hosted by the silicate phases, as concluded above.
- Co is hosted by cobaltite, gersdorffite and to a lesser extent pentlandite.

It should be noted that in the rare cases when mineral chemistry was not available the stoichiometric formula was used (the relevant mineral and petrological descriptions can be found in Chapter 5, and a detailed description of the sulphides and sulpharsenides types and analytical results is provided in Appendix 4). The Ni concentrations in 100% ore minerals (i.e. sulpharsenides + sulphides) were calculated by considering the Ni content and mass fraction of pentlandite, pyrrhotite, chalcopyrite, gersdorffite and cobaltite and individual mineral compositions. The Ni tenor was calculated from the mass fraction of pentlandite,

pyrrhotite, chalcopyrite (all normalised to 100%) and the individual mineral compositions. The results are shown in Table 6.3 and Figure 6.21.

A histogram of Ni wt % for the samples with levels of high arsenic illustrates that Ni wt % (per 100% ore minerals) lies between 11.8 to 14 wt % (Figure 6.22). This is slightly above the Ni wt % (per 100% ore minerals) of the sulphide samples with lower As concentrations, which range from 8.7 to 12 Ni wt% (Figure 6.23). The Ni wt % (per 100% ore minerals) of the low arsenic group is mostly hosted by pentlandite (Figure 6.24), while the Ni in the As rich group is derived from gersdorffite and pentlandite with minor amounts in cobaltite. The less As rich group has an outlier of Ni wt %, above 15; this sample is a relatively fresh ultramafic rock, dominated by olivine and contains some millerite in addition to pentlandite which results in a slight higher Ni wt % (in 100% ore minerals).

Table 6.3. - Sulphide and sulpharsenide percentage normalised to 100 % of the high arsenic samples and their respective Ni tenor.

Samples	Ccp_%	Gers_%	Cob_%	Pn_%	Po_%	Ni concentrations in 100% ore minerals	Ni tenor (%)
C-03	0.2	6.2	2.1	25.4	66.1	13.7	9.5
C-10	0.5	17.9	4.9	25.3	51.5	12.8	10.5
C-12	3.9	1.7	1.4	26.6	66.5	13.1	9.4
C-14	0.2	8.2	0.7	18.6	72.3	13.6	7.0
C-16	0.4	1.8	1.1	22.9	73.8	13.5	8.2
C-18	1.3	18.2	0	24.4	56.1	12.4	9.7
C-20	0.7	1.7	0.7	23.2	73.7	12.9	8.1
C-21	0.3	0	1.6	23.7	74.4	12.3	7.9
C-24	0.3	9	0	24.7	66	14	9.6
C-26	1	2.1	1.3	23.3	72.2	13.3	8.0
C-27	1.6	8.3	0	25.9	64.1	13.4	9.8
C-28	3.2	41.1	0	9.9	45.8	13	5.5
C-29	2.5	25.1	0	17	55.4	13.9	7.8
C-35	0.6	0.5	1.1	24.5	73.2	13.9	8.8
C-36	0.3	1.2	0.9	24.5	73	13.7	8.8
C-37	6.5	20.5	0	17.9	55.1	13.2	7.4
C-45	1.5	1.5	0.8	32	64.2	11.6	10.2
C-47	1	19.4	0.5	30.6	48.5	13.3	13.0
C-49	0.3	17.2	0	15.9	66.6	13.5	6.7
C-50	0.6	26.4	0	18.3	54.7	12.9	7.9
C-52	0.4	6.9	0	27.4	65.2	13.5	10.1

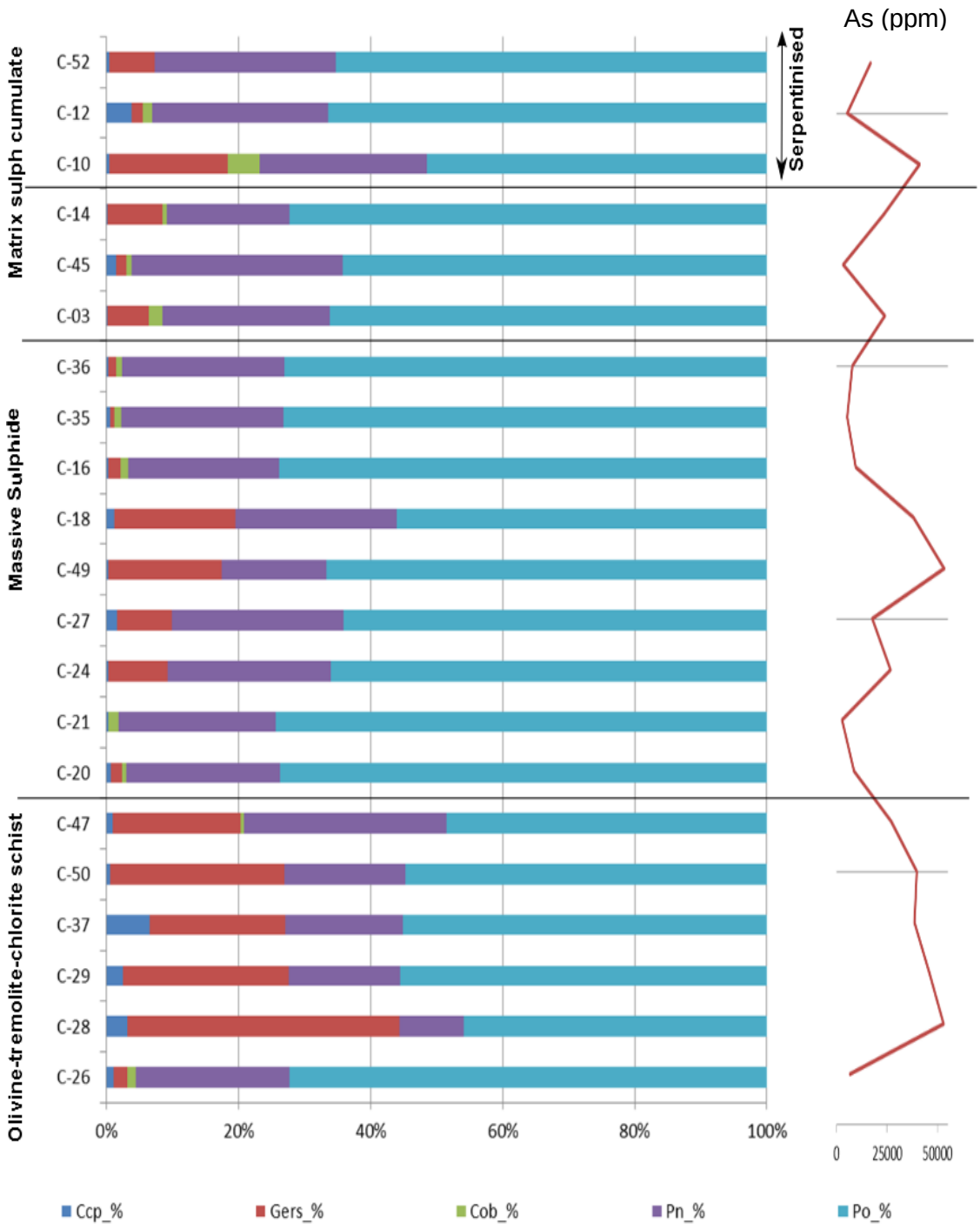


Figure 6.21. - Sulphide and sulpharsenide composition to 100 % (left side, bar chart) of the high arsenic samples and whole rock assay result of As ppm (right side, line chart). Samples are sub-divided by rock type description from Chapter 5.2. (Matrix sulph cumulate represents matrix and disseminated sulphide in olivine-cumulate rock and samples C-10, C-12 and C-52 are the serpentinised variations.

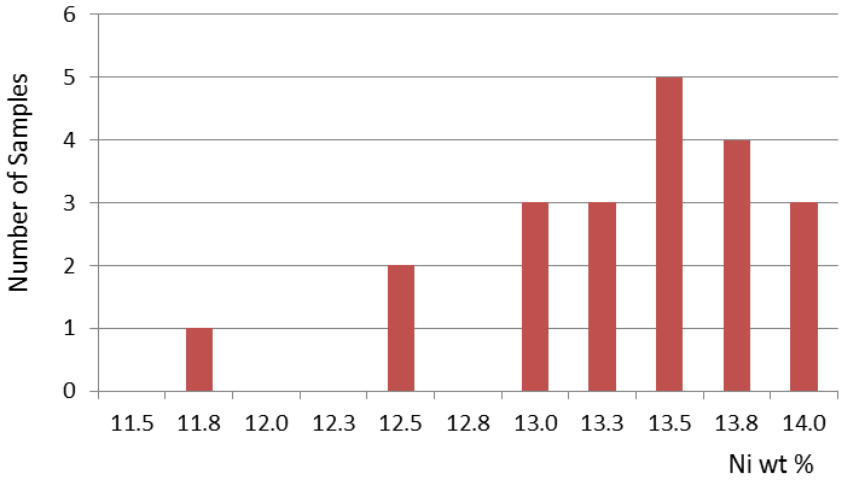


Figure 6.22. - Histogram of Ni wt % (in 100% ore minerals) of the high As samples from the study area.

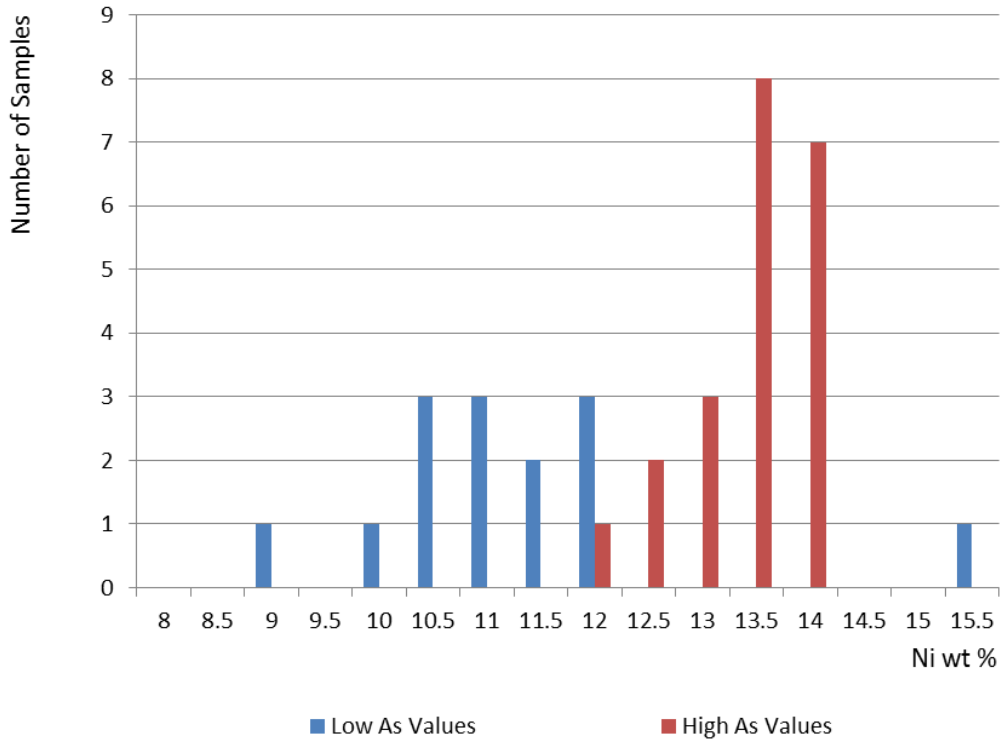


Figure 6.23. - Combined Histograms of Ni wt% (in 100% ore minerals) of the high and low arsenic samples types of the study area. Note the lower Ni wt % for the low As types and higher for the rich As samples. The low arsenic sample plotted at 15.5 wt % Ni is an un-altered sample with millerite (C-60).

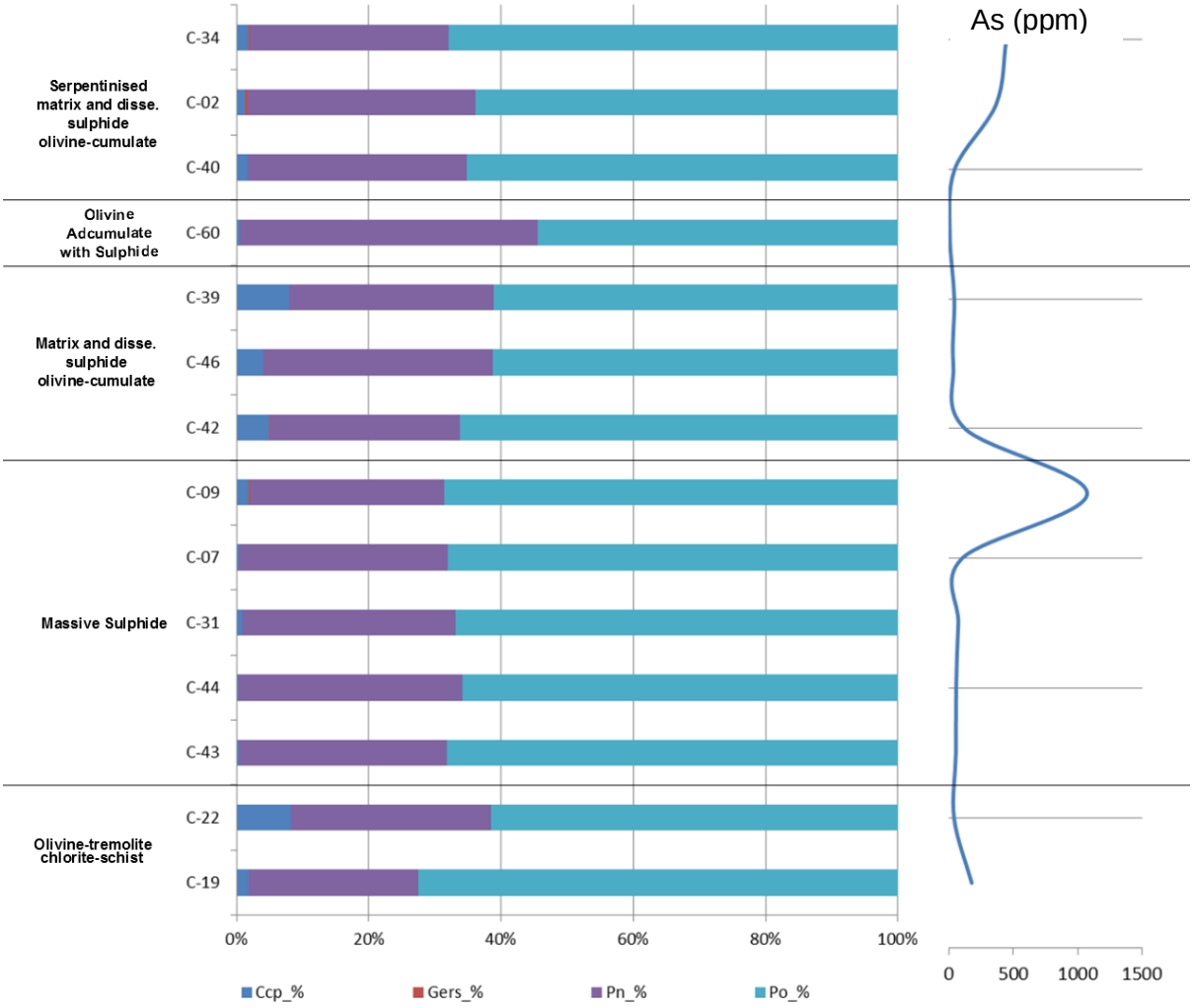


Figure 6.24. - Mineral hosts of Ni to 100 % (left side, bar chart) of the samples with less than 1,100 ppm As and respective whole rock assay result of As ppm shown on the line plot on the right hand side. Samples are sub-divided by rock type description from Chapter 5.2. (Disse. – disseminated)

Based on analysis of As-free samples, Barnes et al (2011) showed that the massive and matrix ores at Perseverance display relatively low Ni tenor (ranging from 9.5 to 11.25 Ni wt % for samples within the matrix zone and around 7.64 Ni wt % for remobilized massive veins like 1A. The majority of the analysed samples from this study are from matrix and disseminated ore and associated massive sulphide veins within the matrix zone, and there is a partial agreement with the results obtained for the low arsenic samples with previous work on Ni tenor at Perseverance (Barnes et al, 2011); see Table 6.4. In contrast, the high arsenic ore types are slightly lower in Ni tenor, ranging from 8.44 to 9.44 Ni wt %, in comparison to low or arsenic “free” samples (Table 6.4). The lower Ni tenor is attributed to Ni associated with sulpharsenides, which reduces the Ni available for the sulphide minerals (Ni tenor calculated to 100% sulphide only).

Table 6.4. - Comparison of Ni tenor from massive sulphide veins with the matrix ore, matrix and disseminated in olivine-sulphide cumulates (from serpentine to olivine rich rocks) and from areas containing sulpharsenide-bearing mineral from the Perseverance deposit. Note the slightly lower Ni tenor for samples with higher amounts of As in comparison to similar low As rocks at the deposit, due to the Ni enrichment within the sulpharsenides. Measurements with (*) are from Barnes et al (2011) and the 1A orebody represents samples from remobilized massive sulphide veins. Oli-Tre-Chlo Rocks is abbreviation for olivine-tremolite-chlorite schists.

	Massive veins within matrix ore	Matrix	Oli-Tre-Chlo rocks close to matrix ore	Massive veins within matrix ore	Matrix	Oli-Tre-Chlo rocks close to matrix ore	Matrix	Massive veins within matrix ore	Massive Breccia
	Main Orebody	Main Orebody	Main Orebody	Main Orebody	Main Orebody	Main Orebody	Main Orebody	Main Orebody	1 A orebody
	low As	low As	low As	high As	high As	high As			
Ni (wt %)	9.99	10.99	11.17	8.62	9.44	8.44	9.13	11.25	7.64
Standard Deviation	0.94	0.79	0.62	1.01	1.42	2.33	NP	NP	NP
#samples	4	6	2	9	5	7	9 (*)	3 (*)	5 (*)

6.5. Summary of the geochemical analyses of sulpharsenides and Ni tenor

- Cobalt is mostly present in the sulpharsenide mineral series and other sulphides only contain trace levels of this element in areas of high arsenic concentration. The low or absent amounts of Co in sulphides may be related to alteration and remobilization; Co may have been remobilized and concentrated within the arsenic-bearing minerals. However, as all microanalyses were carried using SEM EDS, the detection limit is not particularly low, so some samples of sulphide, especially pentlandite, may have held low Co concentrations. Also, the concept that all Co is located within arsenic-bearing minerals is not valid in areas with low amounts of arsenic, because in these areas Co may be associated with sulphide minerals as shown on the diamond drillhole striplog and geochemical data from Appendix 2, on holes 949-44, 949-46, 951-1, 951.-3, 951-4 and 951-5, where there are peaks of Co in zones of low to absent arsenic.
- Nickel is mostly hosted by sulphides and sulpharsenides. Previous microprobe analysis of silicate minerals at Perseverance has not detected Ni in silicates at the Perseverance main orebody within the study area (Barnes et al, 2011).

- Cobaltite has, in general, less variable Co and Ni values than gersdorffite, and the interpretation of the cobaltite temperature of crystallisation suggests that most cobaltite was crystallised at temperatures higher than 500 ºC (considering the minimum temperature equilibrium of the plots on the ternary FeAsS-CoAsS-NiAsS system of Klemm, 1969). Gersdorffite on the other hand, contains more variable Co and Ni values and the interpretation of gersdorffite data suggests that this mineral crystallised at a wide range of temperatures, with minimum temperatures from approximately 550 ºC to 250 ºC (taken from minimum temperature of equilibrium shown on the ternary FeAsS-CoAsS-NiAsS system of Klemm, 1969). Crystallisation of arsenic-bearing minerals, especially those with minimum temperature of crystallisation above 550 ºC, can potentially be associated with the peak metamorphism. Gole et al (1987) estimated the temperature of the prograde peak metamorphic event to be 535°C to 560°C (±50 ºC).
- The Ni wt % in 100% ore minerals (i.e. sulpharsenides + sulphides) of the selected samples show two main trends, which are mostly related to the whole-rock As concentration. The higher Ni wt % (in 100% ore minerals) is associated with high arsenic concentrations with Ni wt % (in 100% ore minerals) ranging between 11.8 to 14 wt %, while the rock types with lower As concentrations generally range between 8.7 to 12 Ni wt % (in 100% ore minerals). The Ni wt % (in 100% ore minerals) of the low arsenic concentration types is found almost entirely within pentlandite and minor gersdorffite, while Ni in samples with higher arsenic concentration is hosted by gersdorffite and pentlandite with a small fraction held in cobaltite.

7. SULPHUR ISOTOPES

No sulphur isotope studies of sulpharsenide minerals at the Perseverance deposit have been carried out prior to this work. Also, all previous study of arsenic-bearing minerals focussed only on the massive sulphide veins and their enclosing rocks in structurally complex zones (Davies, 1996) which are mostly located along shear zones with altered metamorphic/hydrothermal rocks adjacent to satellite massive sulphide deposits 1A and F2 (Figure 2.5, Chapter 2).

This study focuses on sulphur isotopes within the main disseminated and semi-massive (matrix sulphide) ultramafic komatiite ore body of the PUC, the massive sulphide lenses located within the main disseminated ore body, the remobilised massive sulphide veins located in metasediments (footwall rocks) and later coarse gersdorffite in shear zone located within the PUC, via analysis of arsenic-bearing minerals (gersdorffite) and sulphides (pyrrhotite, pentlandite and chalcopyrite). The purpose of the sulphur isotope study was to determine the origin of sulphur in the sulpharsenides and sulphides to potentially give additional insights on the origin of the sulpharsenides. Ten minerals separated from eight ore samples were selected for sulphur isotope analyses. Sampling, analytical techniques and results are provided in Appendix 5. The samples comprised:

- Three pyrrhotite with no oxidation present (samples C-19, C-44, C-09);
- Two pentlandite with no oxidation present (samples C-44 and C-09);
- Three coarse grained gersdorffite, from shear zones within heavily disseminated ultramafic (semi-massive) and massive sulphide rocks (samples C-14 and C-50 for disseminated sulphide and C-49 for a massive sulphide) and from the lower temperature type.
- Two sulphides in microveins in the biotite schist rocks (footwall metasediments). These sulphides are interpreted to have been possibly remobilized by later events (Chapter 2): one non-magnetic pyrrhotite (sample C-05) and chalcopyrite (sample C-08).

The sulphur isotope analytical data for the Perseverance deposit is presented in Table 7.1 and illustrated in Figure 7.1. The pyrrhotite has values of $\delta^{34}S$ from -5.00 to -3.76 ‰ and pentlandite $\delta^{34}S$ values are -4.13 and -3.09 ‰. The remobilized

chalcopyrite and pyrrhotite have $\delta^{34}S$ values of -3.32 and 2.65 ‰ respectively and the gersdorffite ranges in $\delta^{34}S$ from -3.65 to -3.10 ‰.

Table 7.1 Sulphur isotope data for massive sulphide, remobilized sulphide in veins and later coarse gersdorffite in shear zone samples from the Perseverance deposit (basal portion of PUC). Analysis from the CSL, University of Tasmania (Appendix 5). Rock type legend: Vein/Metas (massive sulphide veins in metasediments), M$ (massive sulphide), Alt M$ (partially altered massive sulphide), TCO$ (Tremolite-chlorite-olivine rocks with heavily disseminated sulphide) and Alt Matrix$ (altered ultramafic with heavily disseminated sulphide or semi-massive sulphide).

CSL No.	Sample ID	Mineral	$\delta^{34}S$ (permil)	Rock Type
12041	C 05	pyrrhotite	**-2.65**	Vein/Metas
12042	C 08	chalcopyrite	**-3.32**	Vein/Metas
12043	C 09	pyrrhotite	**-3.76**	M$
12044	C 09	pentlandite	**-3.09**	M$
12045	C 14	gersdorffite	**-3.65**	Alt Matrix$
12046	C 19	pyrrhotite	**-5.00**	TCO$
12047	C 44	pyrrhotite	**-4.38**	M$
12048	C 44	pentlandite	**-4.13**	M$
12049	C 49	gersdorffite	**-3.10**	Alt M$
12050	C 50	gersdorffite	**-3.31**	TOC$

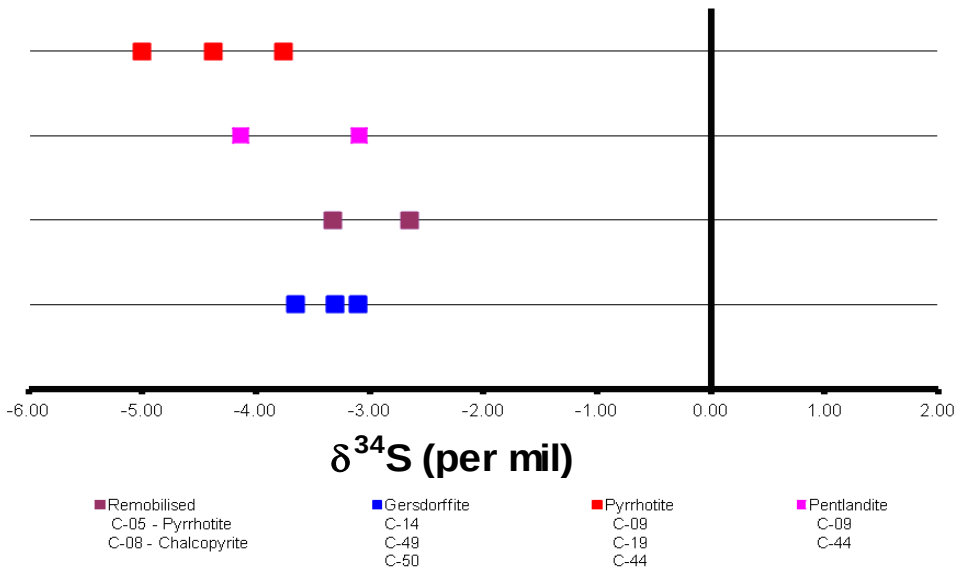


Figure 7.1. - Distribution of the sulphur isotope data for sulphide and sulpharsenides from the Perseverance deposit.

7.1. Interpretation of sulphur isotope data and comparison with other nickel sulphide deposits

Previous sulphur isotope studies in Ni-Cu sulphide deposits have been used to constrain and potentially determine the sulphur source(s), for nickel sulphides associated with komatiites, komatiitic basalts, and ultramafic-mafic intrusions (e.g. Naldrett 1981; Lesher, 1989 and Fiorentini et al, 2012). Komatiites require a near-surface crustal sulphur source to produce nickel sulphide mineralization (e.g. Naldrett, 1973 and 1981, Fiorentini et al. 2010). Lesher (1989) showed that the baseline PGE concentrations of komatiites worldwide supports the view that these magmas most likely reached surface and erupted while under-saturated in sulphide.

The Perseverance deposit is evidence for a continuity of genetic processes between types 1 and 2 ores (Fiorentini and Beresford, 2004, and Barnes et al, 2011). Type 1 nickel sulphide deposits contain both massive and matrix or net-textured sulphide ore and are similar to deposits found at Kambalda, Raglan and Thomson (Fiorentini and Beresford, 2004). Type 2 ores have textural features similar to those found at the Mount Keith deposits, with very low amounts of disseminated sulphides (Barnes et al, 2011). Type 1 deposits tend to be those in which high arsenic concentrations are found at the deposit scale, are commonly located in or at the base of preferred lava pathways or magma conduits (Gresham and Loftus-Hills, 1981). The nickel sulphide mineralisation style at Perseverance deposit has been associated with a genetic model that include thermo-mechanical erosion and assimilation of a sulphide-bearing substrate during prolonged lava flow based on primary trace element and isotopic geochemistry (Lesher and Campbell, 1993). Addition of sulphur could be linked to assimilation or devolatilisation of sulphidic sediments in the crust, or from massive exhalative sulphides, or both (Fiorentini and Beresford, 2004). During the ascent of the magma and its eruption the magma may assimilate crustal elements, especially sulphur. If the source of sulphur is a sedimentary rock, the source may contain anomalous amounts of heavy or light sulphur (Fiorentini and Beresford, 2004).

The samples of pyrrhotite and pentlandite obtained in this study show slightly depleted $\delta^{34}S$ from -5.00 to -3.09 ‰, while gersdorffite also exhibits negative $\delta^{34}S$ values between -3.65 and -3.10 ‰. The negative $\delta^{34}S$ obtained in this work is compatible with other similar nickel sulphide ore associated with komatiitic basalts in the Agnew-Wiluna Greenstone Belt (Figure 7.2). The negative $\delta^{34}S$ values of this study may indicate a sulphur source from sulphides contained within sedimentary

rocks. There are documented occurrences of extremely fine-grained carbonaceous pelites that have been interpreted as metamorphosed black shales, located south of the Perseverance deposit (Sharp, 1996), that could represent the source of sulphur.

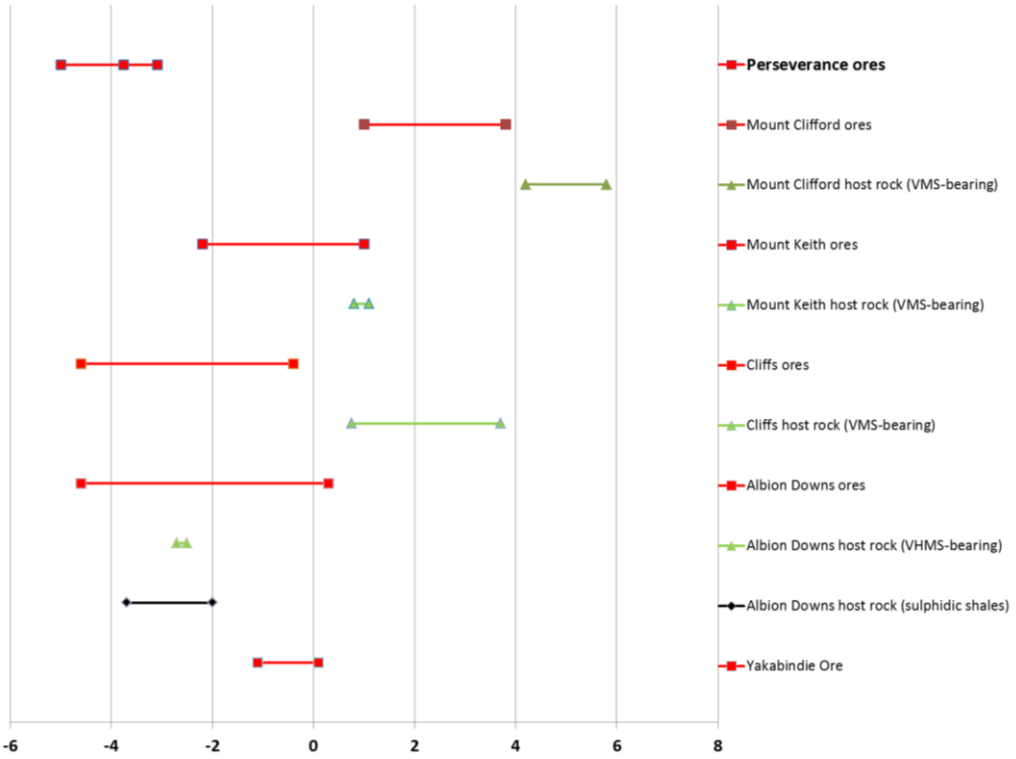


Figure 7.2. - Compilation of $\delta^{34}S$ data for nickel sulphide deposits associated with komatiites from the Agnew-Wiluna Greenstone Belt. Data from Perseverance deposit is from this study whereas Mount Clifford, Mount Keith, Cliffs, Albion Downs and Yakabindie data is from Bekker et al (2009) in Fiorentini et al (2012). Data for nickel sulphide ores are shown in red, for VMS-bearing host rocks in green, and sulphidic shale host rocks in black.

Sulphur isotope compositions from several other Ni-S nickel sulphide deposits are presented for comparison in Table 7.2 and illustrated in Figure 7.3. Examples of hydrothermal pyrite in gold deposits in the Eastern Goldfields Province, Yilgarn (proximal to the study area) have been added to Table 7.2 and are illustrated in Figure 7.3 for comparison with the Ni sulphide ore types.

The $\delta^{34}S$ values for black shales at Blair nickel deposit (Brabham 2005) and other shales in the Agnew-Wiluna belt (Bekker et al, 2009) also have a negative $\delta^{34}S$, and this implies that some sulphur from the sedimentary black shales could have been locally assimilated by the magma.

However, recent work on multiple sulphur isotopes in Archean sedimentary and igneous rocks has concluded that $\delta^{34}S$ data only is not enough for a determination of the environment of formation and any interpretation based on this should be made with caution (Farquhar et al, 2010). The studies of Bekker et al (2009) and Fiorentini et al (2012) applied multiple sulphur isotope techniques ($\delta^{34}S$ and $\delta^{33}S$ based on mass-dependent and mass-independent sulphur isotope geochemistry) and addressed the S source of komatiite-hosted Ni-Cu-(PGE) deposits in the Norseman-Wiluna and Abitibi greenstone belts. These authors confirmed that the sulphur source for the Agnew-Wiluna greenstone belt deposits was derived from country rock sulphides and not from a mantle source. However, the authors also stated that the similarity in $\delta^{34}S$ isotope values between komatiites and country rock sulphides in Archean terranes does not necessarily reflect an assimilation signature, but could be due to a similar spread of $\delta^{34}S$ values in Archean magmatic and sedimentary sulphides.

Fiorentini et al (2012) concluded that volcanic hosted hydrothermal massive sulphides in footwall felsic volcanic sequences of the Agnew-Wiluna greenstone belt komatiites are the source of S for large high-tenor komatiite-hosted Ni-Cu-(PGE) sulphide deposits, mostly type 1, rather than sulphide-bearing black shales.

According to Fiorentini et al (2012), all the largest deposits in the Agnew-Wiluna greenstone belt occur in proximal association with coherent felsic volcanic units and pyrite-rich, low-temperature hydrothermal exhalative sulphides. Fiorentini et al (2012) suggest that the mineralisation at Cliffs represents a significant anomaly, in that its $\delta^{34}S$ values are notably different from those of the pyrite-rich exhalative sulphides located at the footwall of the Cliffs ultramafic unit. This discrepancy is presently not fully understood. The Perseverance deposit contains similar $\delta^{34}S$ value ranges to that of the Cliffs deposit (Figures 7.2 and 7.3 and Table 7.2), indicating, possibly, similar sulphur sources to sulphur at the Cliffs deposit.

Table 7.2 Analysed $\delta^{34}S$ isotope data from nickel sulphide deposits (Fe-Ni sulphides) and gold deposits (pyrite only) in the Eastern Goldfields Province, Yilgarn, Western Australia. Data that does not provide minimum and maximum values published is marked as "NP".

Deposit	$\delta\ ^{34}S_{‰}$	Min $\delta\ ^{34}S_{‰}$	Max $\delta\ ^{34}S_{‰}$	Reference
Archean flow-related komatiites (Type 1 deposits)				
Perseverance	-3.8	-5	-3.09	
Cliffs	NP	-4.6	-0.4	Fiorentini et al (2012)
Area 57	1.5	0.23	3.17	Brabham (2005)
Blair	2	0.84	2.42	Brabham (2005)
Langmuir Nº 2	0.3	NP	NP	Naldrett (1989)
Langmuir Nº1	-1.9	NP	NP	Naldrett (1989)
O'Toole	5.7	5.25	6.83	Choudhuri et al (1997)
Archean dunite lens komatiites (Type 2 deposits)				
Mt. Windarra	-1.9	NP	NP	Naldrett (1989)
Mount Clifford	NP	1	3.8	Fiorentini et al (2012)
Mount Keith	NP	-2.2	1	Fiorentini et al (2012)
Yakabindie	NP	-1.1	0.1	Fiorentini et al (2012)
Albion Downs	NP	-4.6	0.3	Fiorentini et al (2012)
Proterozoic komatiites				
Donaldson West	3.5	NP	NP	Naldrett (1989)
Manitoba	4.1			Naldrett (1989)
Sudbury				
Little Stobie 1	1.08	NP	NP	Naldrett (1989)
Little Stobie 2	0.46	NP	NP	Naldrett (1989)
Levack West	2.58	NP	NP	Naldrett (1989)
Levack Main Ore	3.13	NP	NP	Naldrett (1989)
Gold deposits in the Eastern Goldfields Province, Yilgarn				
Sunrise Dam	1.1	-8.2	4	Hodkiewicz et al (2008)
North Royal	4.1	0.3	10.4	Hodkiewicz et al (2008)
Golden Kilometre	3.2	-4.3	3.4	Hodkiewicz et al (2008)
Great Eastern	0.9	-0.6	2.6	Hodkiewicz et al (2008)
Lady Boutiful	3.2	-1.1	9.5	Hodkiewicz et al (2008)
Hunt	3.9	1	8	Hodkiewicz et al (2008)
New Celebration	3	-8.6	5.5	Hodkiewicz et al (2008)
Porphyry	3.1	-10.2	10	Hodkiewicz et al (2008)

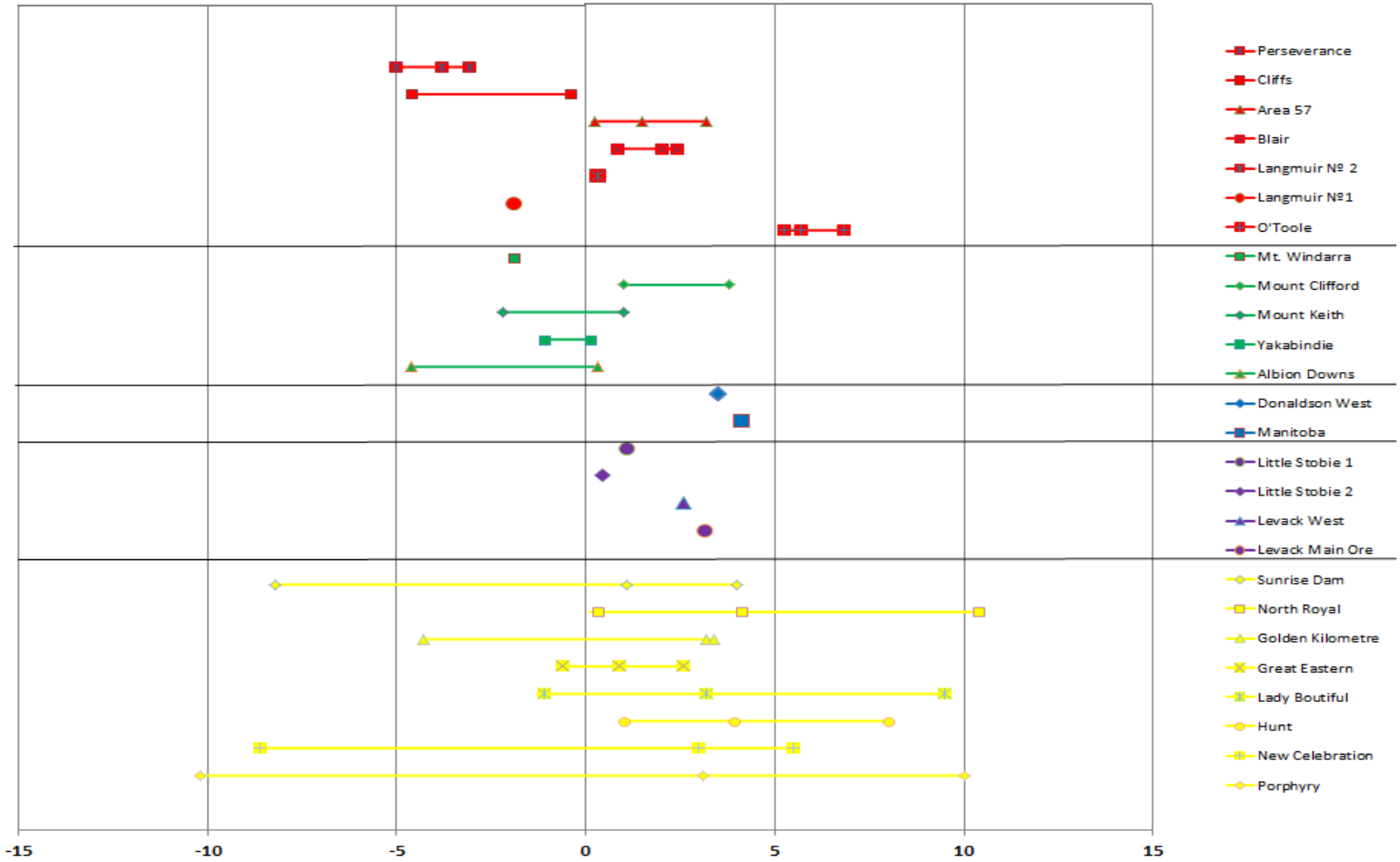


Figure 7.3. Diagram shows the distribution $\delta^{34}S$ at selected major magmatic sulphide nickel ore deposits and pyrite in gold deposits of the Eastern Gold Province. References and values are in table 7.2. Archean flow-related komatiites (Type 1 deposits) are shown in red, Archean dunite lens komatiites (Type 2 deposits, with disseminated sulphide mineralisation only) are shown in green, Proterozoic komatiites are shown in blue, Sudbury nickel deposits are shown in purple and gold deposits in the Eastern Goldfields Province, Yilgarn are shown in yellow.

7.2. Summary of the sulphur isotope study

The following summarises the sulphur isotope data from sulphides and sulpharsenides from the Perseverance deposit:

- All minerals analysed for $\delta^{34}S$, including sulphide and sulpharsenide samples, fall within a similar range, with $\delta^{34}S$ ranging from -5 to -2.65 ‰ (mean of -3.76 ‰) while sulpharsenide samples $\delta^{34}S$ range from -3.65 to -3.1 ‰ (mean of -3.53 ‰). The overlapping ranges may suggest a similar source of sulphur for all sulphide and sulpharsenides in the PUC.
- The sulphur isotope values from Perseverance deposit are similar to some other Ni-S deposits in the Agnew-Wiluna greenstone belt (Fiorentini et al 2012) and sulphur saturation into the komatiite magma has been attributed to assimilation of country rock sulphides rather than only evolution of magmas containing only sulphur originally derived from the mantle (Fiorentini et al 2012).
- The negative $\delta^{34}S$ values obtained from the sulphides and sulpharsenides in this study are consistent with sulphur sourced from sulphides from sedimentary rocks. However, recent multiple sulphur isotope analyses of $\delta^{34}S$ and $\delta^{33}S$ carried out at the Agnew-Wiluna greenstone belt indicate that volcanic hosted hydrothermal massive sulphides in footwall felsic volcanic sequences of the Agnew-Wiluna greenstone belt komatiites are the source of sulphur for the large and high-tenor komatiite-hosted Ni-Cu-(PGE) sulphide deposits rather than sulphide-bearing black shales (Fiorentini et al, 2012).
- Multiple sulphur isotope analyses of $\delta^{34}S$ and $\delta^{33}S$ could not be applied to the samples from this study. However, as also documented by Fiorentini et al (2012), the mineralisation at Cliffs ore represents a significant anomaly in $\delta^{34}S$ values, in that the sulphur isotopes from this deposit are notably different from those of the pyrite-rich exhalative sulphides located at the footwall of the Cliffs ultramafic unit. This discrepancy is not fully understood and the $\delta^{34}S$ values are similar to those from the Perseverance deposit. Further sulphur isotope studies are recommended to better understand the sulphur provenance for the Perseverance deposit and to compare it with the other deposits from the Agnew-Wiluna greenstone belt.

8. GENETIC MODEL FOR ARSENIC MINERALISATION AND CONCLUSIONS

8.1. Genetic model for arsenic enrichment at the Perseverance deposit

Arsenic abundances in natural basaltic liquids saturated in immiscible sulphide and arsenide melts are low, and separation of As-rich melts tends not occur even after extensive crystallisation of the magma (Wood, 2003). Arsenic concentrations in magmatic melts can significantly increase via assimilation of As-rich country rocks (e.g. As-rich shales) by the magmas (Gervilla et al, 1996; Gervilla et al, 1998; Hanley, 2007; Dare et al, 2010; Godel et al, 2012 and Pina et al, 2013). The contaminated magmas could then reach sufficiently high As concentrations to segregate arsenide droplets by immiscibility. Sulpharsenides of magmatic origin have been described in the Rosie Nickel Prospect, Duketon Belt in Western Australia (Godel et al, 2012) and other rock types and environments, which include Iherzolite from Malaga, Spain (Gervilla and Ronsbo, 1992), spessartite in Montagne Noire, France (Beziat et al, 1996) and Dundonald Beach South in the Abitibi Sub province, Canada (Hanley, 2007).

Saturation of sulphur in komatiites associated with the Perseverance deposit has been documented to be due to assimilation of country rock sulphides, rather than evolution of a magma containing only mantle-derived sulphur (Fiorentini et al, 2012), and arsenic could potentially have been added by a similar assimilation process. Black shales containing sulphides and carbonaceous matter tend to be high in arsenic (Onishi and Sandell, 1955), with concentrations of 20 to 200 ppm in sulphide-rich and/or black shales (Sherwood, 2005). There are occurrences of extremely fine-grained carbonaceous pelites that have been interpreted as metamorphosed black shales, which are located south of the Perseverance deposit (Sharp, 1996).

Studies from Barnes (1998) considered that the lack of chromite at Perseverance Deposit was due to anomalously reducing conditions in the crystallizing lava. However, high amounts of chromite interpreted to be cumulus on textural grounds occur in localised areas at the base of the Perseverance ultramafic sequence. This chromite is mostly associated with tremolite-chlorite-olivine rocks (also known as schists), corresponding to komatiite liquid and olivine orthocumulate compositions with the tremolite-chlorite schists representing metakomatiites (modified original chilled margins or A zones of flows) and olivine-tremolite-chlorite schists

corresponding to olivine orthocumulate. The olivine orthocumulate rock types described above are slightly lower in MgO than the extremely pure olivine-sulphide cumulate and olivine-adcumulate with essentially no trapped komatiite liquid component. These margins or A zones of flows and olivine orthocumulate types are also generally associated with sulpharsenides and could be related to cumulates which nucleated at the floor of the lava flow (Barnes, 1998). This portion of the deposit could be associated with a small trap, where the lava was more static and accumulated crystals early, due to less turbulent conditions, possibly where the magma was located in embayments or in a depression at the base of preferred lava pathways or magma conduits. According to Barnes (1998), this type of environment is more conducive to the equilibrium growth and accumulation of euhedral chromite crystals (Chapter 6). Similar chrome spinel, often rimmed by chlorite and magnetite, is a common accessory in tremolite-chlorite-bearing lithologies, and is strongly zoned from chromite cores to ferri-chromite rims. Such spinel has been noted to be associated with the arsenic-rich zones at the study area. However, all chromites from the areas rich in arsenic were metamorphosed to amphibolite facies, resulting in their enrichment in Fe and depletion in Ni and Cr, compared to magmatic types (Barnes, 2000). Also, no pristine euhedral igneous magnesiochromite without magnetite alteration was identified, which also supports the lack of preservation of magmatic mineral compositions in the study area. The anomalous arsenic content within the matrix ore and massive sulphide veins within the matrix ore at the Perseverance deposit could potentially be due to country rock assimilation and have been present during the magmatic stage. However, this hypothesis is hard to prove as there is no clear evidence found during this analysis to support it, due to the effects of the prograde peak metamorphic event on the rocks of the study area, which resulted in a complete overprint of the primary features.

Alternatively, since arsenic is soluble in aqueous fluids even at low temperatures (Smedley and Kinniburgh, 2002), the addition of As into the PUC could have occurred during an influx of H_2O into the ultramafic complex which resulted in the early, pre-amphibolite facies metamorphism, serpentinisation of the PUC. The interpreted crystallisation of arsenic-bearing minerals (especially for the examples with minimum temperature of crystallisation above 550 ºC) can be associated with peak metamorphism. Gole et al (1987) estimated the temperature of this prograde peak metamorphic event to be 535°C to 560°C, based on garnet-biotite

geothermometry. Maximum pressures are considered to be around 3 kbar (Figure 8.1).

All the arsenic-bearing minerals found at the Perseverance deposit can also be related to structures and mineralogy that are related to post magmatic process, as they are mainly present as re-crystallised minerals in shear zones or in intensely altered rocks. In the altered komatiite rocks, the most common gangue minerals associated with gersdorffite are calcite and dolomite with chlorite and in some cases minor amounts of talc. According to Gole et al (1987) and Fiorentini and Beresford (2004) this pattern of alteration to calcite + dolomite + chlorite with minor talc represents an alteration of a komatiitic protolith by CO_2-rich fluids. The pervasive talc-carbonate alteration commonly occurs near major shear zones at the base of the Perseverance ultramafic complex (Chapters 2, 3 and 4), which could have been the channel for CO_2-bearing fluids that obliterated primary komatiite textures. With respect to mobility of elements, Fiorentini and Beresford (2004) suggest that As tends to be easily dissolved and remobilized by metamorphic fluids. The assemblage talc-magnesite has an upper stability limit of about 550ºC (±50ºC) and under peak conditions at Perseverance, talc-carbonate rocks would have broken down to either olivine-carbonate or olivine-talc assemblages, depending upon the ratio of talc to carbonate in the protolith (Gole et al, 1987), illustrated on Figure 8.1. However, evidence of late hydrothermal carbonate alteration is also present by the occurrence of carbonates (mostly calcite) along shears and altering silicates, which could be associated with late As-CO_2 alteration, especially when considering the lower temperature sulpharsenide types. As such, evidence exists for two stages of carbonate alteration and it is unclear how these relate to the arsenic alteration (pre-and metamorphic and/or hydrothermal CO_2).

The timing of enrichment of arsenic in the Perseverance Ultramafic Complex is unclear. Arsenic enrichment could, potentially, have occurred at any time from magmatism to peak metamorphism, including early serpentinisation and early talc-carbonate alteration. The higher temperature arsenic-bearing mineral enrichment is now overprinted by retrograde events. Events subsequent to the As enrichment have overprinted all potential evidence of arsenic influx at the study area and the arsenic is now concentrated along major shears and altered zones, which are also associated with hydrothermal carbonate alteration, related to stages of late As-CO_2 alteration (Figure 8.1).

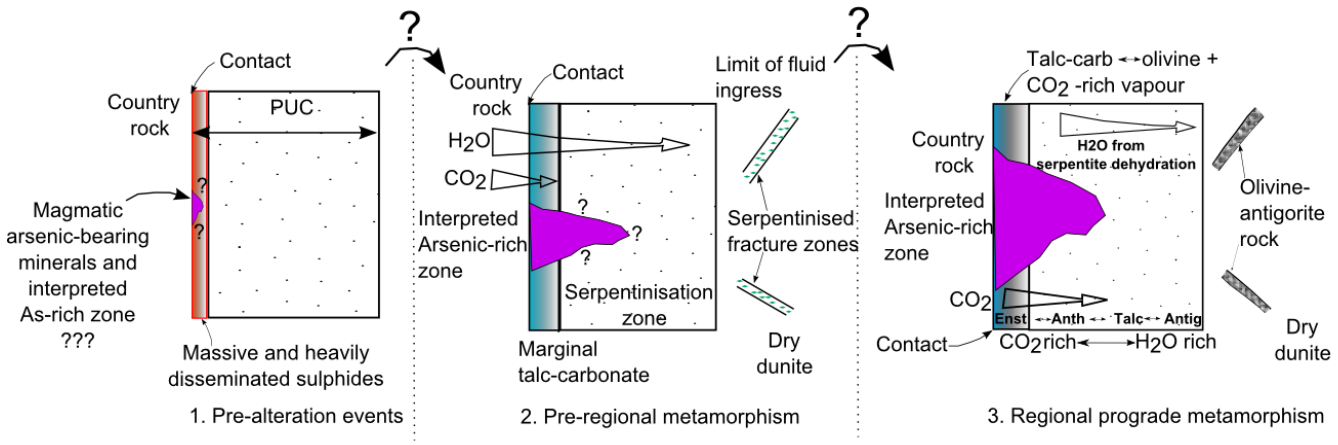


Figure 8.1. - Interpreted timing and location of arsenic enrichment at the PUC with As distributed between the basal contact and anthophyllite zone of the peak metamorphism (based on petrology descriptions of arsenic-bearing minerals in association with anthophyllite). Influx of arsenic into the ultramafic complex is unclear; however it was most likely to be present in the PUC prior to or during pre-regional metamorphism. Model for generation of metamorphic mineral zonation modified after Gole et al, (1987) involving formation of an outer talc-carbonate rind (2) and breakdown of talc-carbonate and serpentine during prograde metamorphism (3).

8.2. Conclusions

High arsenic concentrations within the Perseverance orebody were previously only known in the massive sulphide ore shoots and along the footwall massive sulphide rocks in areas with intense shearing. These are commonly seen along the small massive sulphide pods abutting the contact of Perseverance Ultramafic Complex and Footwall rocks, and along massive sulphide shoots like 1A, 1B and 1C, and F2. It was thought that the main matrix sulphide mineralisation was arsenic free. However, based on this study, it has been confirmed that the arsenic zone is not only confined to the remobilized massive sulphides and that it is also found within the main matrix and heavily disseminated sulphide ore of PUC.

Samples with high arsenic found within the matrix and heavily disseminated nickel mineralisation include ultramafic rocks that are derived from: (1) extremely pure olivine-sulphide adcumulate/mesocumulate protolith; (2) olivine-tremolite-chlorite rocks (corresponding to metamorphosed komatiite flows, whose variation in present olivine content reflecting an original alternation of spinifex textured A zones and olivine-enriched cumulate B-zones, classification from Gole et al, 1987). These ultramafic rocks are also located in intense sheared zones and associated

with remobilized massive sulphide veins); and (3) veins or breccias of massive sulphide within the matrix ore. The protoliths (olivine-sulphide adcumulate/mesocumulate, komatiite and massive sulphides) are now represented by a series of rocks that have been subject to later metamorphic and/or metasomatic alterations

Cobalt is dominantly hosted by the sulpharsenide mineral series, with other sulphides only containing trace levels of this element in areas of high arsenic concentration. The low amount of Co in sulphides may be related to alteration and remobilization, during which Co was remobilized and concentrated within the arsenic-bearing minerals. Due to the analytical technique utilized for the microanalyses (SEM EDS), Co could be present in sulphides in low concentrations (below 1% within the grain assayed), but was not detected by the analyses. Also, the concept that all Co is located within arsenic-bearing minerals is not valid in areas with low amounts of arsenic since in these areas Co displays a sulphide association.

Cobaltite has, in general, less variable Co and Ni values than gersdorffite, and the interpretation of cobaltite minimum crystallisation temperatures suggests that most of the cobaltite crystallised at temperatures higher than 500 ºC. Gersdorffite on the other hand, contains more variable Co and Ni values, and the interpretation of gersdorffite data suggests that their minimum crystallisation temperature varies within a wide range from approximately 550 ºC down to 250 ºC. The interpreted crystallisation of arsenic-bearing minerals with minimum temperature of crystallisation above 550 ºC is interpreted here to be associated with the peak metamorphism.

The Ni wt % in 100% ore minerals (i.e. sulpharsenides + sulphides) of the selected samples show two main trends, which are generally related to the whole-rock As concentration. The higher Ni wt % (in 100% ore minerals) is associated with high arsenic concentrations, with Ni wt % (in 100% ore minerals) ranging between 11.8 to 14 wt %, while the rock types with lower As concentrations generally range between 8.7 to 12 Ni wt % (in 100% ore minerals). The Ni of the low arsenic concentration types is found almost entirely within pentlandite and minor gersdorffite, while Ni in the higher arsenic concentration samples is related to gersdorffite and, to a lesser extent, to cobaltite and pentlandite.

The source of arsenic and its influx into the Perseverance Ultramafic Complex remains unclear. It may be linked to any event from magmatism to peak

metamorphism, including early serpentinisation and talc-carbonate alteration that occurred prior to peak metamorphism. Evidence of the potential earlier processes is now overprinted by metamorphic and metasomatic events. The late events are commonly related to hydrothermal carbonate alteration which is present in the study area by the occurrence of later carbonates (mostly calcite) along shears. The late alteration event could be associated with CO_2 rich fluids, especially when associated to the lower temperature sulpharsenide types.

There are confirmed occurrences of black shales around the deposit that could have provided arsenic via assimilation processes, as black shales containing sulphides and carbonaceous matter tend to be high in arsenic. However, there is not a clear link between the black shales and the PUC. Felsic rocks dominate the sequence of country rocks between the black shales and PUC (not including remobilized massive sulphides from PUC into the felsic rocks) and these rocks do not contain high levels of arsenic.

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APPENDIX 1. Sample catalogue and selection

Sixty-one core slab samples and three samples from development mining headings were sent to Minerex (Esperance) for the preparation of thin sections, polished thin sections and polished blocks.

The following tables include the list of samples and type of sections per sample, brief rock description, samples selected for geochemical (XRF); mineralogical (XRD); scan electron microscopy (SEM) and sulphur isotope analyses, coordinate (local coordinate system), and a summary of analytical results per sample.

A.1 - Physical Preparation and Analytical Techniques

Analytical Method Description for Leinster Suite 60 (Al_2O_3, As ,Co ,Cr, Cu, Fe, MgO, Ni, S):

- 0.1 g of sample weighed into Teflon test tube.
- Addition of mixed acid. (nitric, perchloric and hydrofluoric acids)
- Digested in a “Hot Box” overnight through a series of increasing temperatures from 20º C to 220o C.
- Mineral salts leached in hydrochloric acid
- Volumed by auto dispenser
- Aliquot of solution read by ICP-OES.

Analytical Method Description for Leinster Suite 60 (NSNi):

- 0.5g of sample into plastic vial.
- Addition of perchloric/hydrofluoric acid mixture.
- Digested at room temperature for 60 minutes, swirling at 20 minute intervals.
- Addition of 10 ml boric acid.
- Transfer to 50 ml volumetric flask and make-up to the mark.
- Aliquot of solution read by ICPOES

Analytical Procedure:

- Client details and Analytical Request Sheet (ARS) instructions entered into Laboratory Information Management System (LIMS) computer database.
- Correct method for analytical instructions selected, and sample strings entered into LIMS computer database.
- Worksheets generated by LIMS that display all relevant data needed by laboratory personnel. LIMS selects random position of standards and identity and random position of replicates.
- Samples weighed into test tubes and catch weight recorded in LIMS computer database.
- Samples digested according to method instructions.
- Digested samples leached and then volumed with a diluent containing an internal standard – usually Lutetium (Lu).
- Sample solutions decanted into small plastic test tubes that fit auto-sampler trays.
- Sample solutions read for selected elements by Inductively Coupled Plasma Optical Emission Spectrometer. (ICPOES)
- Laboratory Supervisor or Senior Laboratory Technician performs frontline Quality Control. (QC)
- Samples above upper limit selected for re-assay.
- Blank, standards and replicates checked for pass/fail.
- Internal standard checked for instrumental drift.
- Samples above upper limit re-assayed by beaker digestion.
- Any QC failures decanted from solutions and re-read.
- Samples re-assayed if re-read solutions fail QC.
- Laboratory Manager or Senior Chemist validates QC before reporting results to the client. Random check assays or any QC failures missed during frontline QC are done.
- Analytical results reported electronically to client in requested format.
- All analytical data compressed and archived and analytical results saved on ZIP disk.

Table A.1 Standard samples expected values and Standard Deviation

Method & Constituent	LNO5-1		LNO5-2		LNO5-3		LNO5-4		LNO5-5	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Fusion (XRF, ICPOES)										
Aluminium Oxide, Al_2O_3 (wt%)	2.04	0.08	0.852	0.046	0.355	0.025	0.307	0.049	0.674	0.042
Chromium, Cr (ppm)	972	72	571	92	303	93	1005	93	2031	99
Iron, Fe (wt%)	8.04	0.44	10.08	0.39	12.94	0.63	22.86	1.10	34.11	0.79
Magnesium Oxide, MgO (wt%)	38.44	0.77	41.11	0.83	40.17	0.98	26.15	0.49	14.61	0.28
Nickel, Ni (wt%)	0.891	0.03	1.43	0.06	2.00	0.04	3.53	0.06	5.10	0.13
Four Acid (ICPOES/ICPMS/AAS)										
Arsenic, As (ppm)	<20	IND	<30	IND	<50	IND	41	13	124	13
Cobalt, Co (ppm)	197	13	256	20	360	26	753	54	1147	74
Chromium, Cr (ppm)	626	202	394	139	232	83	696	52	1348	179
Copper, Cu (ppm)	381	12	745	19	1047	28	1374	25	1768	36
Iron, Fe (wt%)	7.85	0.27	9.98	0.33	12.74	0.46	22.49	0.70	34.90	0.97
Nickel, Ni (wt%)	0.868	0.03	1.40	0.06	1.96	0.06	3.47	0.10	5.11	0.19
Sulphur, S (wt%)	2.13	0.08	3.72	0.36	6.19	0.27	14.1	0.59	20.8	1.8

Figure A.1 – Sample Process Flowchart

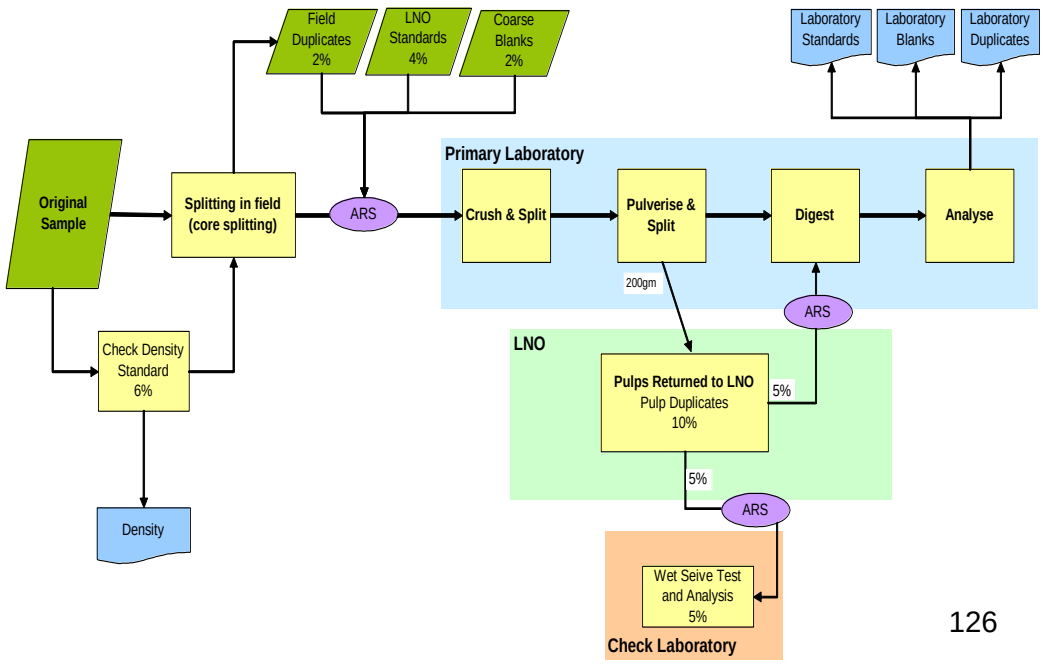


Table A1.1 Sample type list containing hole/mining face id and rock description

SAMPLE TYPE	SAMPLE CODE	SAMPLE ID - ASSAY	HOLE ID	FROM	TO	ROCK DESCRIPTION
CORE	C-01	LD274490	949-51	54.4	55.2	ULTRAMAFIC DISS +CARB+MASSIVE SULPHIDES
CORE	C-02	LD274492	949-51	55.4	55.6	ULTRAMAFIC DISS +CARB+MASSIVE SULPHIDES
CORE	C-03	LD274488	949-51	54.9	55.0	CARB+SULPHIDES AND CLASTS OF ULTRAMAFIC
CORE	C-04	LD273092	949-50	27.0	28.9	FELSIC
CORE	C-05	LD273093	949-50	28.9	29.2	QUARTZ VEIN AND MASSIVE SULPHIDE
CORE	C-06	LD273094	949-50	29.2	29.4	CONTACT ULTRAMAFIC |+ FELSIC AND MASSIVE SULPHIDE
CORE	C-07	LD273368	949-49	57.5	57.7	MASSIVE SULPHIDE
CORE	C-08	LD273282	949-49	10.7	10.9	FELSIC + BIOTITE QUARTZ VEIN + MASSIVE SULPHIDE
CORE	C-09	LD273283	949-49	10.9	11.2	MASSIVE SULPHIDE
CORE	C-10	LD273306	949-49	21.2	21.4	MASSIVE SULPHIDE + CARBONATES
CORE	C-11	LD273305	949-49	20.9	21.2	ULTRAMAFIC + MASSIVE SULPHIDE
CORE	C-12	LD273287	949-49	11.8	12.1	ULTRAMAFIC ALTERED +MASSIVE SULPHIDE+CARBONATES
CORE	C-13	LD273281	949-49	10.5	10.7	FELSIC + QUARTZ VEIN
CORE	C-14	LD261367	951-1	41.5	41.8	ULTRAMAFIC ALTERED +MASSIVE SULPHIDE+CARBONATES
CORE	C-15	LD260679	951-3	52.0	53.9	ULTRAMAFIC DISS
CORE	C-16	LD260680	951-3	53.9	54.3	ULTRAMAFIC DISS
CORE	C-17	LD260682	951-3	54.3	54.7	MASSIVE SULPHIDE
CORE	C-18	LD274660	949-44	36.6	37.0	ULTRAMAFIC DISS + CARB
CORE	C-19	LD274666	949-44	40.8	41.1	MASSIVE SULPHIDE
CORE	C-20	LD274659	949-44	35.6	36.6	ULTRAMAFIC DISS + CARB
CORE	C-21	LD274657	949-44	34.6	35.6	MASSIVE SULPHIDE
CORE	C-22	LD274667	949-44	41.1	41.3	FELSIC+ULTRAMAFIC

Table A1.1 Sample type list containing hole/mining face id and rock description

SAMPLE TYPE	SAMPLE CODE	SAMPLE ID - ASSAY	HOLE ID	FROM	TO	ROCK DESCRIPTION
CORE	C-23	LD265534	951-4	36.9	38.0	ULTRAMAFIC ALTERED +MASSIVE SULPHIDE+CARBONATES
CORE	C-24	LD265522	951-4	30.9	31.9	ULTRAMAFIC ALTERED +MASSIVE SULPHIDE+CARBONATES
CORE	C-25	LD265521	951-4	30.0	30.9	ULTRAMAFIC ALTERED +MASSIVE SULPHIDE VEINS+CARBONATES
CORE	C-26	LD265532	951-4	35.0	36.5	ULTRAMAFIC ALTERED +MASSIVE SULPHIDE+ SPOTTED CARBONATES
CORE	C-27	LD265518	951-4	29.0	29.5	MASSIVE SULPHIDE + CARBONATES
CORE	C-28	LD265520	951-4	29.5	30.0	ULTRAMAFIC ALTERED +CARBONATES
CORE	C-29	LD265533	951-4	36.5	36.9	ULTRAMAFIC ALTERED +MASSIVE SULPHIDE
CORE	C-30	LD271015	941-90	110.5	111.3	ULTRAMAFIC LOW DISS +SPOTTED CARBONATES
CORE	C-31	LD271016	941-90	111.3	111.5	MASSIVE SULPHIDE + CARBONATES
CORE	C-32	LD265024	951-5	38.2	38.8	ULTRAMAFIC ALTERED +CARBONATES
CORE	C-33	LD265019	951-5	34.4	35.4	ULTRAMAFIC DISS HIGH GRADE AND WEAK CARBONATES
CORE	C-34	LD265028	951-5	40.1	42.0	ULTRAMAFIC DISS
CORE	C-35	LD265021	951-5	36.0	37.4	CARBONATES + MASSIVE SULPHIDES
CORE	C-36	LD265027	951-5	39.3	40.1	ULTRAMAFIC LOW DISS +SPOTTED CARBONATES AND MAGNETITE
CORE	C-37	LD265020	951-5	35.4	36.0	ULTRAMAFIC LOW DISS +SPOTTED CARBONATES
CORE	C-38	LD265026	951-5	39.1	39.3	MASSIVE SULPHIDE
CORE	C-39	LD273129	949-50	64.3	65.2	ULTRAMAFIC DISS AND WEAK CARBONATES
CORE	C-40	LD273113	949-50	52.6	52.8	ULTRAMAFIC DISS
CORE	C-41	LD273116	949-50	54.4	54.8	ULTRAMAFIC LOW DISS +SPOTTED CARBONATES
CORE	C-42	LD273136	949-50	69.2	69.7	ULTRAMAFIC LOW DISS +SPOTTED CARBONATES
CORE	C-43	LD273135	949-50	68.8	69.2	MASSIVE SULPHIDES + ULTRAMAFIC LOW DISS
CORE	C-44	LD273128	949-50	63.6	64.3	MASSIVE SULPHIDES + ULTRAMAFIC LOW DISS
CORE	C-45	LD273120	949-50	56.9	57.3	ULTRAMAFIC DISS

Table A1.1 Sample type list containing hole/mining face id and rock description

SAMPLE TYPE	SAMPLE CODE	SAMPLE ID - ASSAY	HOLE ID	FROM	TO	ROCK DESCRIPTION
CORE	C-46	LD273130	949-50	65.2	65.7	ULTRAMAFIC LOW DISS +SPOTTED CARBONATES
CORE	C-47	LD273119	949-50	56.3	56.9	CARBONATES + ULTRAMAFIC ALTERED
CORE	C-48	LD279972	949-48	15.5	16.5	MASSIVE SULPHIDE
CORE	C-49	LD279975	949-48	16.9	17.3	MASSIVE SULPHIDE + CARBONATES
CORE	C-50	LD280015	949-48	46.1	46.3	ULTRAMAFIC ALTERED +CARBONATES + MASSIVE SULPHIDE
CORE	C-51	LD279089	949-46	30.7	31	ULTRAMAFIC ALTERED +CARBONATES + MASSIVE SULPHIDE
CORE	C-52	LD279090	949-46	31	31.2	MASSIVE SULPHIDE + CARBONATES
CORE	C-53	NS_LPU941-28_0_1	941-28	10.5	11.3	BIOTITE SCHIST
CORE	C-54	NS_LPU941-28_145	941-28	152.300003	154.899994	AMPHIBOLITE
CORE	C-55	LD249711	941-33	195.5	197	CONTACT ULTRAMAFIC + FELSIC AND MASSIVE SULPHIDE
CORE	C-56	NS_LPU941-29_0_1	941-29	125.599998	126.4	MYLONITE
CORE	C-57	NS_LPU941-49A_0_	941-49a	35.400002	39.400002	BIOTITE SCHIST
CORE	C-58	NS_LPU941-49A_0_	941-49a	56	66.099998	RHYODACITE
CORE	C-59	NS_LPU941-49A_0_	941-49a	202.800003	219.699997	MAFIC WITH GARNETS
CORE	C-60	LD249969	941-28	224.100006	226	DUNITE (FINE OLIVINES) - WEAK DISSEMINATED SULPHIDE
CORE	C-61	LD249738	941-33	226	227.699997	DUNITE (FINE OLIVINES) - WEAK DISSEMINATED SULPHIDE
MINE FACE	H-01	PFR29311	9490xc30	-	-	ULTRAMAFIC DISS
MINE FACE	H-02	PFR 29113	9565xc35	-	-	ULTRAMAFIC DISS
MINE FACE	H-03	PFR 29113	9565xc35	-	-	CONTACT FELSIC + ULTRAMAFIC DISS

Table A1.2 Sample coordinate and type of analyses

SAMPLE CODE	X	Y	Z	XRF	XRD	TRL	RP	TL	SEM	S-Iso
C-01	116027	218861	9475	x	x	x			x	
C-02	116027	218861	9475	x	x	x				
C-03	116027	218861	9475	x	x	x			x	
C-04	116001	218862	9490	x	x			x		
C-05	116002	218862	9490	x	x	x				
C-06	116003	218862	9490	x	x	x				
C-07	116046	218873	9494	x	x		x			
C-08	115999	218877	9490	x	x	x			x	
C-09	115999	218877	9490	x	x		x		x	x
C-10	116010	218876	9491	x	x	x			x	
C-11	116009	218876	9491	x	x	x				
C-12	116000	218877	9490	x	x	x			x	
C-13	115999	218877	9490	x	x			x		
C-14	116034	218869	9514	x	x	x			x	x
C-15	116038	218870	9487	x	x	x				
C-16	116039	218870	9486	x	x	x			x	
C-17	116039	218870	9486	x	x		x		x	
C-18	116041	218950	9487	x	x	x			x	
C-19	116045	218950	9487	x	x	x				x
C-20	116041	218950	9487	x	x	x			x	
C-21	116040	218950	9487	x	x		x		x	
C-22	116046	218950	9487	x	x		x			
C-23	116040	218914	9509	x	x	x				
C-24	116034	218914	9509	x	x	x			x	
C-25	116033	218914	9509	x	x	x			x	
C-26	116039	218914	9509	x	x	x			x	
C-27	116032	218914	9510	x	x	x			x	
C-28	116033	218914	9509	x	x	x			x	
C-29	116040	218914	9509	x	x	x			x	
C-30	116022	218884	9408	x	x	x				
C-31	116022	218884	9408	x	x		x		x	
C-32	116040	218913	9502	x	x	x				
C-33	116037	218913	9503	x	x	x				
C-34	116043	218913	9501	x	x	x				
C-35	116038	218913	9502	x	x	x			x	
C-36	116041	218913	9501	x	x	x			x	
C-37	116037	218913	9502	x	x	x			x	
C-38	116041	218913	9501	x	x		x		x	
C-39	116038	218861	9491	x	x	x				
C-40	116026	218861	9491	x	x	x				
C-41	116028	218861	9491	x	x	x				

Table A1.2 continued. Sample coordinate and type of analyses

SAMPLE CODE	X	Y	Z	XRF	XRD	TRL	RP	TL	SEM	S-Iso
C-42	116043	218860	9491	x	x	x				
C-43	116042	218860	9491	x	x	x				
C-44	116037	218861	9491	x	x	x				x
C-45	116031	218861	9491	x	x	x			x	
C-46	116039	218861	9491	x	x	x				
C-47	116030	218861	9491	x	x	x			x	
C-48	116010	218906	9482	x	x		x			
C-49	116011	218906	9482	x	x	x			x	x
C-50	116039	218906	9472	x	x	x			x	x
C-51	116026	218906	9491	x	x	x				
C-52	116026	218906	9491	x	x	x			x	
C-53	115924	218941	9399					x		
C-54	116039	218942	9315					x		
C-55	116052	218972	9255	x				x		
C-56	116025	218938	9341					x		
C-57	115929	219053	9376					x		
C-58	115944	219055	9358					x		
C-59	116026	219067	9233					x		
C-60	116095	218941	9271	x	x	x				
C-61	116070	218975	9231	x	x	x				
H-01	116008	218909	9487	x		x				
H-02	116036	219004	9588	x		x				
H-03	116036	219004	9588	x		x				

The following is the list of abbreviations used:

- C-XX – Sample number (core slab)
- H-XX – Sample number (hand sample)
- XFR - X-ray Fluorescence Spectrometry
- XRD - X-ray powder diffraction analyse
- TL – transmitted section
- RP . - reflected polished block
- TRL – transmitted and reflected light section
- SEM –scan electron microscopy
- S-iso – sulphur isotope analyse

Table A1.3 Geochemical analytical results

SAMPLE CODE	Al_2O_3 (%)	As (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	MgO (%)	Ni (%)	S (%)	SiO2 (%)	CaO (%)	Cl (ppm)
C-01	0.20	28263	5910	309	380	37	3.6	10.26	32.4	5.6	0.7	<100
C-02	0.30	365	600	1140	1000	18.3	31.6	2.52	9.5	25.9	0.2	1044
C-03	0.60	23923	4200	569	540	30.5	10.5	7.11	23.8	17.6	0.5	262
C-04	13.00	16	5	66	100	3.8	0.9	0.02	0.3	70.6	4	870
C-05	9.00	240	400	209	3300	10.8	2.6	0.89	6.6	56.4	6.7	807
C-06	1.10	4012	300	460	2800	8.2	24.5	0.54	2.9	51.3	5.8	810
C-07	0.10	99	1700	919	900	40.6	10.2	7.13	30.2	8.2	0.7	261
C-08	3.80	529	1300	1244	18300	25	6.6	3.37	16.6	32.8	3.8	<100
C-09	0.10	1071	2800	994	5100	49.2	0.9	8.12	37	2.4	1.3	<100
C-10	1.40	41090	8810	1013	710	19.6	15.3	5.45	13.8	13.9	9.7	2317
C-11	0.90	8464	1600	1858	500	26.1	15.6	2.67	16.4	14.8	9.2	922
C-12	0.80	5228	1300	6066	6200	24.1	19.8	4.43	16.5	19.6	3.4	315
C-13	12.30	10	500	500	200	4.5	0.9	0.03	0.5	72.1	3	<100
C-14	0.94	23300	4200	1463	500	31.8	12.1	5.32	22.1	22.3	0.1	1900
C-15	3.40	1505	700	4027	1900	20	27.9	2.36	9.7	25.6	1.9	204
C-16	0.94	9623	2400	1827	1000	39.1	8.6	6.58	28	10.6	1.1	<100
C-17	1.51	6917	1700	536	1300	27.2	22.3	4.3	17	19.8	0.9	191
C-18	1.10	38120	3200	20713	2700	33.4	9.6	7.02	21	8.7	6.3	923
C-19	3.90	175	1100	1221	3300	37.3	4.1	4.56	24.1	14.8	7.4	<100
C-20	1.10	8666	2100	7389	2000	45	3.5	7.05	31	5.9	2.6	<100
C-21	0.10	2711	2100	1495	1000	51.7	0.6	7.73	37.9	1	1.2	<100
C-22	13.30	38	200	78	2600	14	1.8	0.93	4	38.6	21.1	<100
C-23	2.64	2621	900	916	2200	22.7	23.2	2.74	11.9	22.7	2.3	1377

Table A1.3 continued. Geochemical analytical results

SAMPLE CODE	Al_2O_3 (%)	As (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	MgO (%)	Ni (%)	S (%)	SiO2 (%)	CaO (%)	Cl (ppm)
C-24	3.02	26877	2800	6064	900	38.6	7	8.36	27.3	6.9	3.1	189
C-25	3.02	14704	1800	1562	4300	24.7	17.8	4.09	15.2	22.2	3.3	338
C-26	1.89	6745	1500	1340	1600	26.7	20	3.79	15.8	20.6	1.6	506
C-27	4.72	17836	1900	8561	2900	28.1	11.2	5.77	18.8	17.8	6.3	<100
C-28	5.10	53013	2000	6033	4200	18.6	17.3	4.46	11.3	24.5	7.7	<100
C-29	2.08	45888	2500	1333	4200	26.6	13.4	5.89	16	26.3	2.8	<100
C-30	4.00	1556	400	7265	1200	12.5	24	1.58	6.1	40.6	3.2	529
C-31	1.00	71	1800	3954	2200	41.7	5.6	7.2	29.8	9.1	2.2	708
C-32	2.08	11975	1700	626	2000	26.5	19.8	4.16	16.2	22.9	1	218
C-33	1.89	2444	1000	946	2500	24.9	21.4	3.38	15.2	23.2	1.9	506
C-34	0.57	444	700	661	1900	22.5	27.1	3.04	13.4	22.6	0.4	1179
C-35	1.70	5432	1800	3834	1700	40.6	6.5	6.89	28.3	8.4	3	<100
C-36	0.76	7996	2200	985	800	43.6	5.2	7.67	31.1	5.9	2.1	113
C-37	4.91	38634	2500	3550	10100	24.5	15.6	4.73	15	20.6	5.1	<100
C-38	0.19	984	1800	522	400	50.9	0.7	9.44	37.3	0.9	1.1	<100
C-39	0.30	40	700	802	7300	20.8	28.3	2.74	11.6	24	1.3	2415
C-40	0.20	43	500	894	1100	17.1	32.2	2.05	8.2	25.4	0.1	2588
C-41	2.20	4605	900	8666	600	20.3	25.6	2.94	9.2	27.9	0.5	1479
C-42	0.10	123	700	261	3100	14.8	33.3	1.71	8	24.4	4.8	523
C-43	0.20	52	1500	534	800	36	14.3	6.03	25.7	13.6	0.3	533
C-44	0.05	54	1700	1179	700	49.4	1.9	9.51	36.9	1.8	0.7	1499
C-45	1.10	3228	1000	540	1700	20.9	24.9	3.42	11.8	21.9	2.6	1442
C-46	0.90	32	400	1710	2000	15	32.9	1.68	6.3	28.1	3.2	2341

Table A1.3 continued. Geochemical analytical results

SAMPLE CODE	Al_2O_3 (%)	As (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	MgO (%)	Ni (%)	S (%)	SiO2 (%)	CaO (%)	Cl (ppm)
C-47	3.7	27086	3970	5286	1090	17.9	21	4.71	10.6	16.8	4.3	1000
C-48	0.1	1027	2200	1149	1400	51.6	0.7	8.02	36.8	0.7	1.1	841
C-49	0.1	53158	4500	9448	1000	49.3	1.2	8.73	33.6	1.2	2.1	822
C-50	2.5	39870	2600	6844	900	23.9	16.9	5.26	14.8	20.8	5	653
C-51	2.2	4063	600	7986	9900	12.5	26.5	2.08	7.7	15.1	9.1	1411
C-52	0.7	16932	2100	15387	900	32.8	10.8	6.63	21.3	7.1	6.8	1095
C-53	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C-54	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C-55	16.25	25	8	10	10	2	1.4	0.01	0.02	NS	NS	NS
C-56	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C-57	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C-58	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C-59	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C-60	0.85	5	170	670	70	6.2	58	0.55	1.56	21.9	0.1	NS
C-61	0.47	10	180	830	115	7.4	49.2	0.63	0.13	NS	NS	NS
H-01	0.5	318	700	NS	2000	20.4	26.2	2.79	12	21.5	2.7	1766
N-02	1	36	900	NS	1000	22.8	25.4	3.03	13.7	24.5	0.7	752
N-03	2	39	600	NS	1100	17.2	28.7	1.88	8.9	29	1.4	833

Table A1.4 – Part 1. Mineralogical analytical report per sample

SAMPLE CODE	Actinolite	Alkali Feldspar	Anthophyllite	Arsenopyrite	Biotite	Calcite	Clinochlore	Clinopyroxene	Dolomite	Hematite	Huntite	Magnesite
C-01	<1	<1	5	<1	<1	3	<1	<1	<1	<1	7	<1
C-02	<1	<1	<1	<1	<1	<1	2	<1	1	<1	<1	7
C-03	<1	<1	16	<1	<1	6	2	<1	2	<1	3	2
C-04	3	2	<1	<1	24	<1	<1	<1	<1	<1	<1	<1
C-05	<1	3	<1	<1	3	<1	<1	<1	<1	<1	<1	<1
C-06	<1	7	24	<1	<1	<1	<1	<1	<1	<1	<1	<1
C-07	<1	<1	<1	<1	<1	1	<1	<1	2	<1	<1	<1
C-08	<1	<1	<1	<1	<1	3	4	<1	<1	<1	<1	<1
C-09	<1	<1	<1	<1	<1	3	<1	<1	<1	<1	<1	<1
C-10	<1	<1	<1	<1	<1	17	11	<1	3	<1	<1	<1
C-11	<1	<1	<1	<1	<1	10	3	<1	<1	<1	<1	<1
C-12	<1	<1	<1	<1	<1	4	9	<1	<1	<1	<1	<1
C-13	<1	2	<1	<1	11	<1	<1	<1	<1	<1	<1	<1
C-14	<1	3	16	<1	<1	6	<1	<1	<1	<1	<1	<1
C-15	<1	<1	<1	<1	<1	<1	2	<1	3	<1	<1	<1
C-16	<1	<1	3	<1	<1	3	<1	<1	2	<1	<1	<1
C-17	<1	<1	<1	<1	<1	1	<1	<1	1	<1	<1	<1
C-18	<1	<1	<1	<1	<1	<1	8	<1	<1	<1	<1	<1
C-19	<1	<1	<1	<1	<1	2	2	<1	<1	<1	<1	<1
C-20	<1	<1	<1	<1	<1	3	<1	<1	<1	<1	<1	<1
C-21	<1	<1	<1	<1	<1	3	<1	<1	<1	<1	<1	<1
C-22	<1	<1	<1	<1	<1	1	<1	44	7	<1	<1	<1

Table A1.4 - Part 1 continued. Mineralogical analytical report per sample

SAMPLE CODE	Actinolite	Alkali Feldspar	Anthophyllite	Arsenopyrite	Biotite	Calcite	Clinochlore	Clinopyroxene	Dolomite	Hematite	Huntite	Magnesite
C-23	<1	<1	<1	<1	<1	2	2	<1	<1	<1	<1	<1
C-24	<1	<1	<1	<1	<1	<1	11	<1	8	<1	<1	<1
C-25	<1	<1	10	<1	<1	<1	10	<1	7	<1	<1	<1
C-26	<1	<1	3	<1	<1	2	2	<1	2	<1	<1	<1
C-27	<1	<1	5	<1	<1	<1	10	<1	7	<1	<1	<1
C-28	<1	<1	7	<1	<1	<1	12	<1	10	<1	<1	<1
C-29	<1	<1	25	<1	2	8	<1	<1	3	<1	<1	3
C-30	<1	<1	28	<1	<1	<1	22	<1	<1	<1	<1	<1
C-31	<1	<1	6	<1	<1	<1	6	<1	<1	<1	<1	<1
C-32	<1	<1	11	<1	<1	3	6	<1	<1	<1	<1	<1
C-33	<1	<1	5	<1	<1	1	5	<1	1	<1	<1	<1
C-34	<1	<1	<1	<1	<1	<1	3	<1	<1	<1	<1	<1
C-35	<1	<1	<1	<1	<1	<1	7	<1	5	<1	<1	<1
C-36	<1	<1	<1	<1	<1	4	4	<1	<1	<1	<1	<1
C-37	<1	<1	<1	<1	1	2	7	<1	6	<1	<1	<1
C-38	<1	<1	<1	<1	<1	3	<1	<1	<1	<1	<1	<1
C-39	<1	<1	<1	<1	<1	1	1	<1	3	<1	<1	<1
C-40	<1	<1	<1	<1	<1	<1	2	<1	<1	<1	<1	10
C-41	<1	<1	4	<1	<1	2	10	<1	2	<1	<1	<1
C-42	<1	<1	<1	<1	<1	<1	<1	<1	8	<1	<1	<1
C-43	<1	<1	<1	<1	<1	1	1	<1	<1	<1	<1	<1
C-44	<1	<1	<1	<1	<1	3	<1	<1	2	<1	<1	<1
C-45	<1	<1	2	<1	<1	1	6	<1	8	<1	<1	<1

Table A1.4 - Part 1 continued. Mineralogical analytical report per sample

SAMPLE CODE	Actinolite	Alkali Feldspar	Anthophyllite	Arsenopyrite	Biotite	Calcite	Clinochlore	Clinopyroxene	Dolomite	Hematite	Huntite	Magnesite
C-46	<1	<1	<1	<1	<1	<1	3	3	4	<1	<1	<1
C-47	<1	<1	5	<1	<1	<1	25	<1	14	<1	<1	11
C-48	<1	<1	<1	<1	<1	2	<1	<1	<1	<1	<1	<1
C-49	<1	<1	<1	<1	<1	3	<1	<1	<1	<1	4	<1
C-50	<1	<1	3	<1	<1	<1	9	<1	5	<1	<1	<1
C-51	<1	<1	<1	<1	<1	1	4	<1	17	<1	<1	1
C-52	<1	<1	<1	<1	<1	<1	12	<1	16	<1	<1	<1

Table A1.4 – Part 2. Mineralogical analytical report per sample

SAMPLE CODE	Millerite	Muscovite	Olivine	Orthopyroxene	Pentlandite	Plagioclase	Pyrite	Pyrrhotite	Quartz	Serpentine	Talc	Tremolite
C-01	<1	<1	<1	<1	18	<1	26	34	<1	<1	<0.3	7
C-02	<1	<1	11	<1	6	<1	<1	18	<1	53	<0.3	<1
C-03	<1	<1	8	7	9	<1	<1	20	<1	17	0.8	7
C-04	<1	<1	<1	<1	<1	17	<1	<1	53	<1	<0.3	<1
C-05	<1	6	<1	<1	3	10	<1	22	41	<1	<0.3	12
C-06	<1	<1	<1	<1	1	<1	<1	12	<1	5	1.9	49
C-07	<1	<1	17	<1	17	<1	21	35	<1	7	0.9	<1
C-08	<1	4	7	<1	6	5	14	20	10	<1	5.4	17
C-09	<1	<1	<1	<1	28	<1	10	51	<1	<1	1.9	6
C-10	<1	<1	<1	<1	15	<1	<1	29	<1	26	<0.3	<1
C-11	<1	<1	<1	<1	8	<1	<1	58	1	18	<0.3	<1
C-12	<1	<1	<1	<1	13	<1	<1	26	<1	47	0.8	<1
C-13	<1	<1	<1	<1	<1	14	<1	<1	72	<1	<0.3	<1
C-14	<1	<1	<1	<1	16	<1	7	45	<1	7	<0.3	<1
C-15	<1	<1	55	<1	4	7	<1	13	<1	14	<0.3	2
C-16	<1	<1	19	<1	18	7	<1	43	<1	2	<0.3	3
C-17	<1	<1	51	<1	7	3	7	20	<1	9	<0.3	<1
C-18	<1	<1	<1	<1	19	<1	<1	55	<1	16	<0.3	<1
C-19	<1	<1	<1	<1	14	<1	<1	68	<1	4	<0.3	10
C-20	<1	<1	<1	<1	23	2	<1	59	<1	3	<0.3	9
C-21	<1	<1	<1	<1	25	<1	<1	71	<1	<1	<0.3	<1
C-22	<1	<1	<1	<1	4	5	12	<1	2	<1	<0.3	24
C-23	<1	<1	<1	<1	8	2	<1	34	<1	48	<0.3	<1

Table A1.4 – Part 2. continued. Mineralogical analytical report per sample

SAMPLE CODE	Millerite	Muscovite	Olivine	Orthopyroxene	Pentlandite	Plagioclase	Pyrite	Pyrrhotite	Quartz	Serpentine	Talc	Tremolite
C-24	<1	<1	<1	<1	2	<1	<1	<1	<1	68	<0.3	5
C-25	<1	<1	9	<1	8	<1	<1	20	<1	16	0.5	14
C-26	<1	<1	12	<1	9	3	<1	35	<1	32	<0.3	<1
C-27	<1	<1	<1	<1	12	<1	<1	25	<1	3	2.2	36
C-28	<1	<1	<1	<1	6	<1	<1	12	<1	10	0.8	42
C-29	<1	<1	<1	<1	12	<1	<1	35	<1	1	<0.3	11
C-30	<1	<1	<1	<1	4	<1	<1	10	<1	5	1.9	29
C-31	<1	<1	<1	<1	19	<1	<1	52	<1	3	<0.3	13
C-32	<1	<1	<1	<1	8	<1	<1	34	<1	30	1.3	7
C-33	<1	<1	<1	<1	9	<1	<1	37	<1	32	<0.3	10
C-34	<1	<1	<1	<1	10	<1	<1	30	<1	56	<0.3	<1
C-35	<1	<1	<1	<1	17	<1	3	41	<1	6	<0.3	22
C-36	<1	<1	<1	<1	22	<1	4	50	<1	7	1	10
C-37	<1	<1	8	<1	8	<1	4	17	<1	9	<0.3	33
C-38	<1	<1	<1	<1	27	<1	8	61	<1	<1	<0.3	<1
C-39	<1	<1	40	<1	4	<1	5	17	<1	25	<0.3	2
C-40	<1	<1	<1	<1	7	<1	<1	22	<1	56	<0.3	<1
C-41	<1	<1	13	<1	7	4	<1	25	<1	31	0.5	<1
C-42	<1	<1	57	<1	3	<1	11	9	<1	11	0.6	<1
C-43	<1	<1	26	<1	15	<1	13	29	<1	9	6.1	<1
C-44	<1	<1	<1	<1	26	<1	15	54	<1	<1	<0.3	<1
C-45	2	<1	<1	<1	11	<1	5	30	<1	31	<0.3	<1
C-46	<1	<1	48	<1	3	<1	3	10	<1	22	<0.3	3

Table A1.4 – Part 2. continued. Mineralogical analytical report per sample

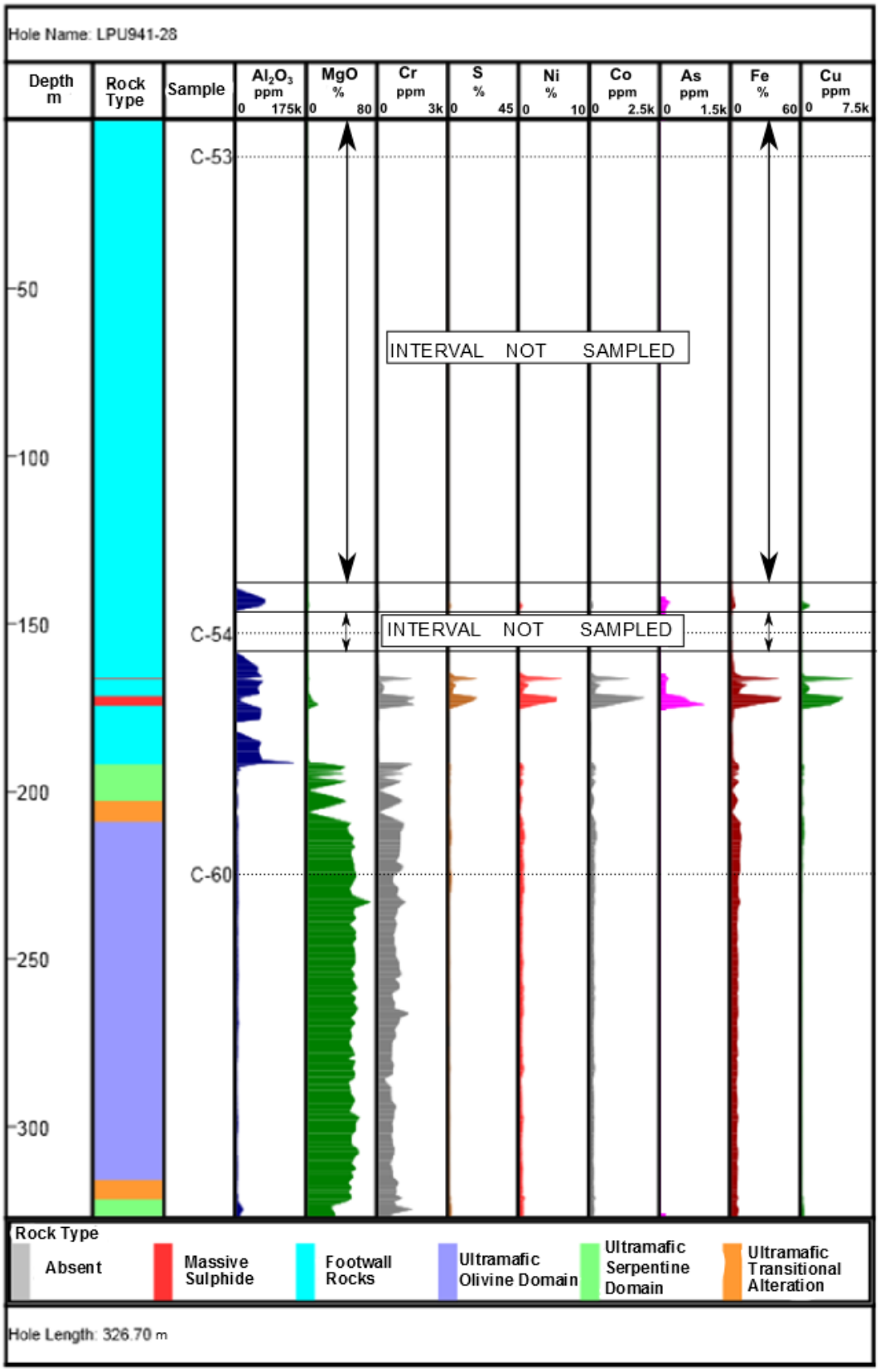
SAMPLE CODE	Millerite	Muscovite	Olivine	Orthopyroxene	Pentlandite	Plagioclase	Pyrite	Pyrrhotite	Quartz	Serpentine	Talc	Tremolite
C-47	<1	<1	<1	<1	7	<1	5	20	<1	11	<0.3	<1
C-48	<1	<1	<1	<1	31	<1	<1	67	<1	<1	<0.3	<1
C-49	<1	<1	<1	<1	29	<1	<1	62	<1	3	<0.3	<1
C-50	<1	<1	6	<1	12	<1	<1	25	<1	10	<0.3	31
C-51	<1	<1	<1	<1	6	<1	<1	19	<1	51	<0.3	<1
C-52	<1	<1	<1	<1	12	<1	<1	59	<1	<1	<0.3	<1

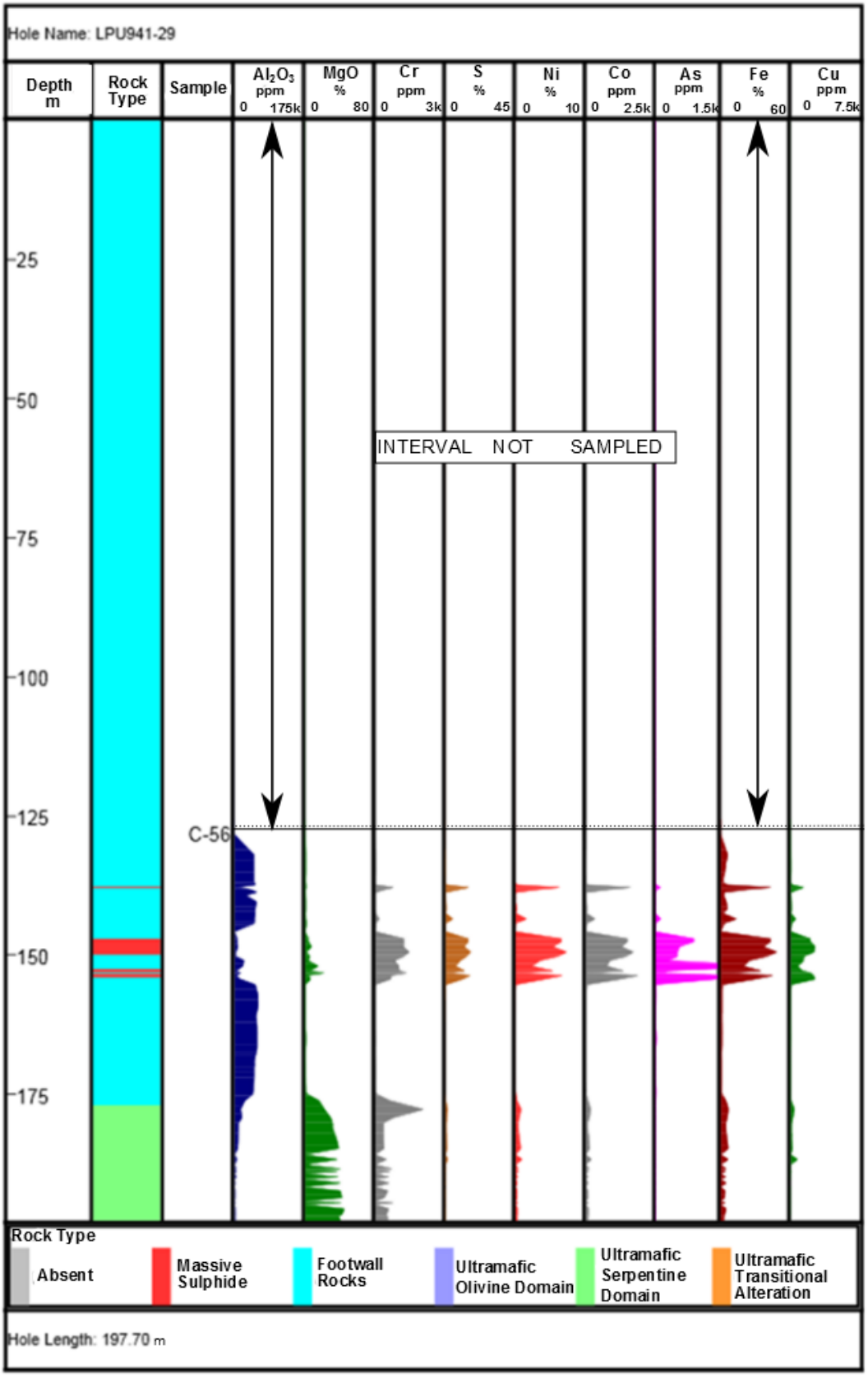
APPENDIX 2. Diamond drillhole striplog and geochemical data

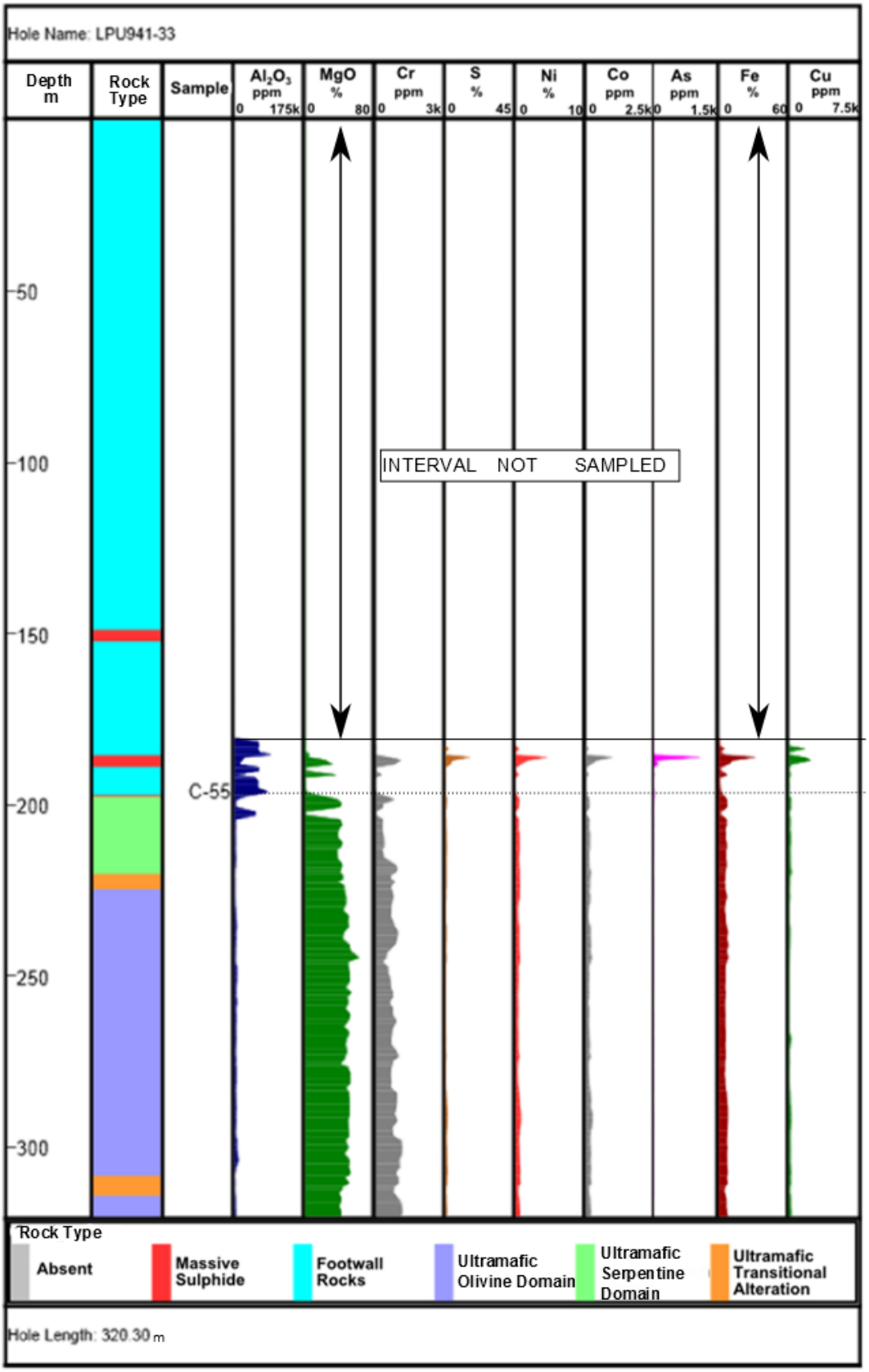
Fifteen diamond drillholes were selected for sampling during this study. All logs were completed by site geologists and analyses were undertaken at the site laboratory. Each drillhole strip log contains the depth, rock type, assays results and position of samples for this study. All Rock types were defined based on the content of massive sulphide logged, ultramafic/felsic contact and on the ultramafic alteration described on Chapter 3, using a split of the ultramafic sample types was completed using three-dimensional surfaces*.* The surfaces were interpreted through the study area based on the XRD data. The general rule applied was that the serpentine domain contained less than 10% olivine, and the olivine domain contained less than 10% serpentine. The transitional domain contained greater than 10% of both mineral species. This is the same practice adopted at the mine site to separate the alteration domains.

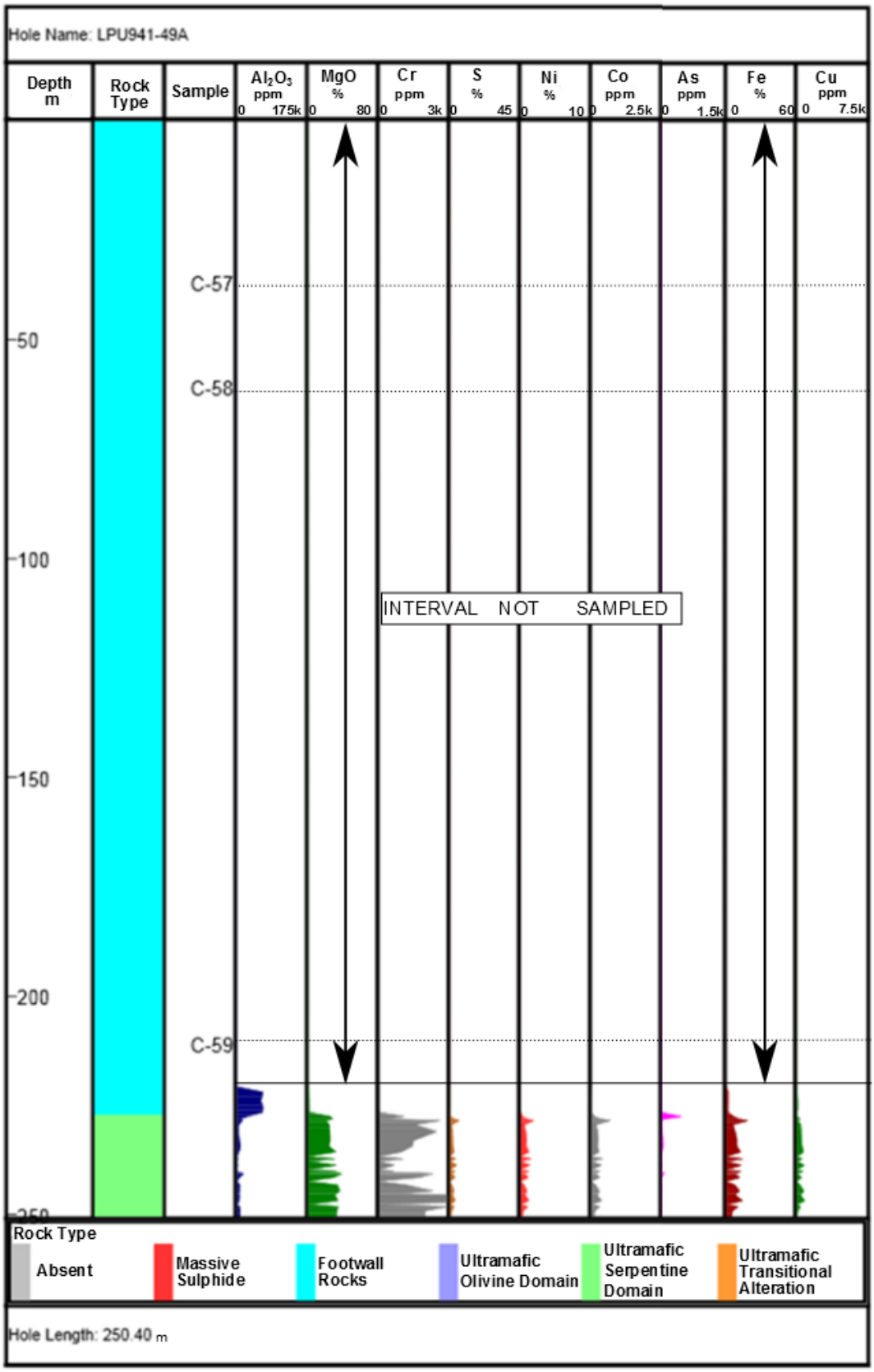
Drillhole ID	Mining Level Collar (RL)
LPU 941-28	9415
LPU 941-29	9415
LPU 941-33	9415
LPU 941-49A	9415
LPU 949-90	9415
LPU 949-44	9490
LPU 949-46	9490
LPU 949-48	9490
LPU 949-49	9490
LPU 949-50	9490
LPU 949-51	9490
LPU 951-1	9515
LPU 951-3	9515
LPU 951-4	9515
LPU 951-5	9515

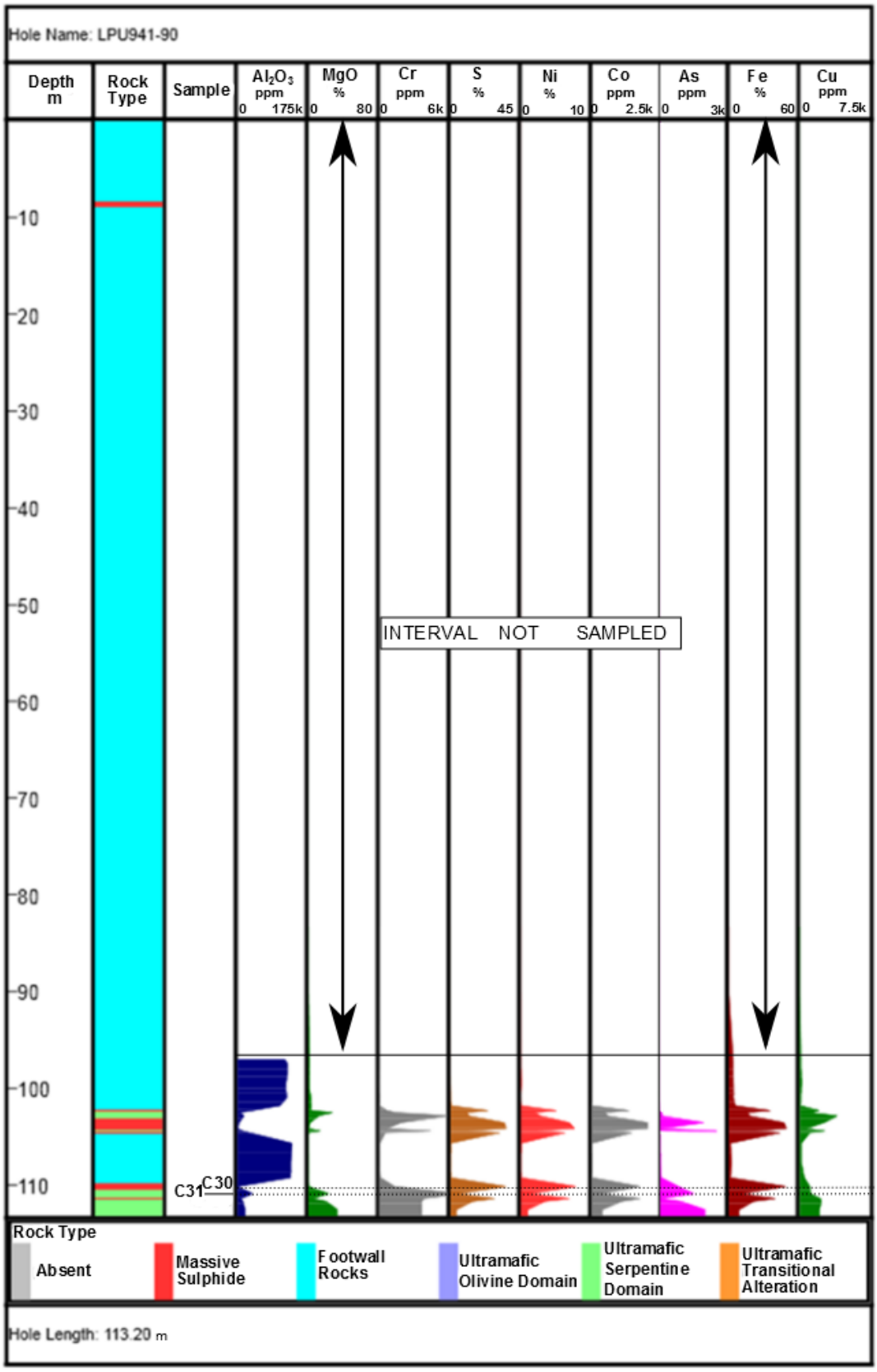
All depth of the drillholes on the strip logs below are in metres and each element is shown with its respective measurement unit (parts per million (ppm) or percentage (%)) and also its specific range. Range scales with k represents thousand's (value*k equal value*1,000).

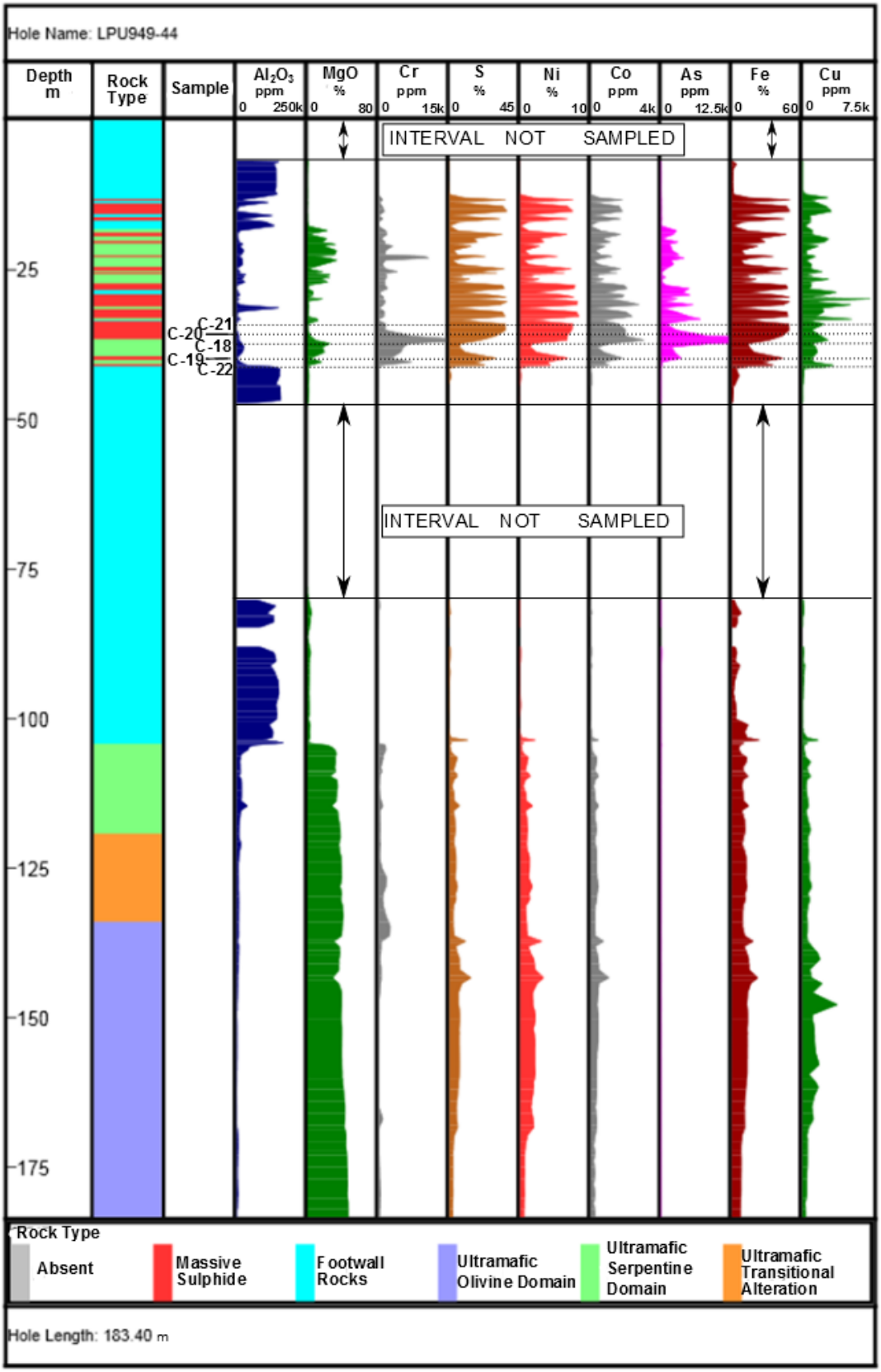

Hole Name: LPU941-28
Depth m
Rock Type
Sample
Al2O3 ppm 0 175k
MgO % 0 80
Cr ppm 0 3k
S % 0 45
Ni % 0 10
Co ppm 0 2.5k
As ppm 0 1.5k
Fe % 0 60
Cu ppm 0 7.5k
C-53
C-54
C-60
50
100
150
200
250
300
INTERVAL NOT SAMPLED
INTERVAL NOT SAMPLED
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 326.70 m

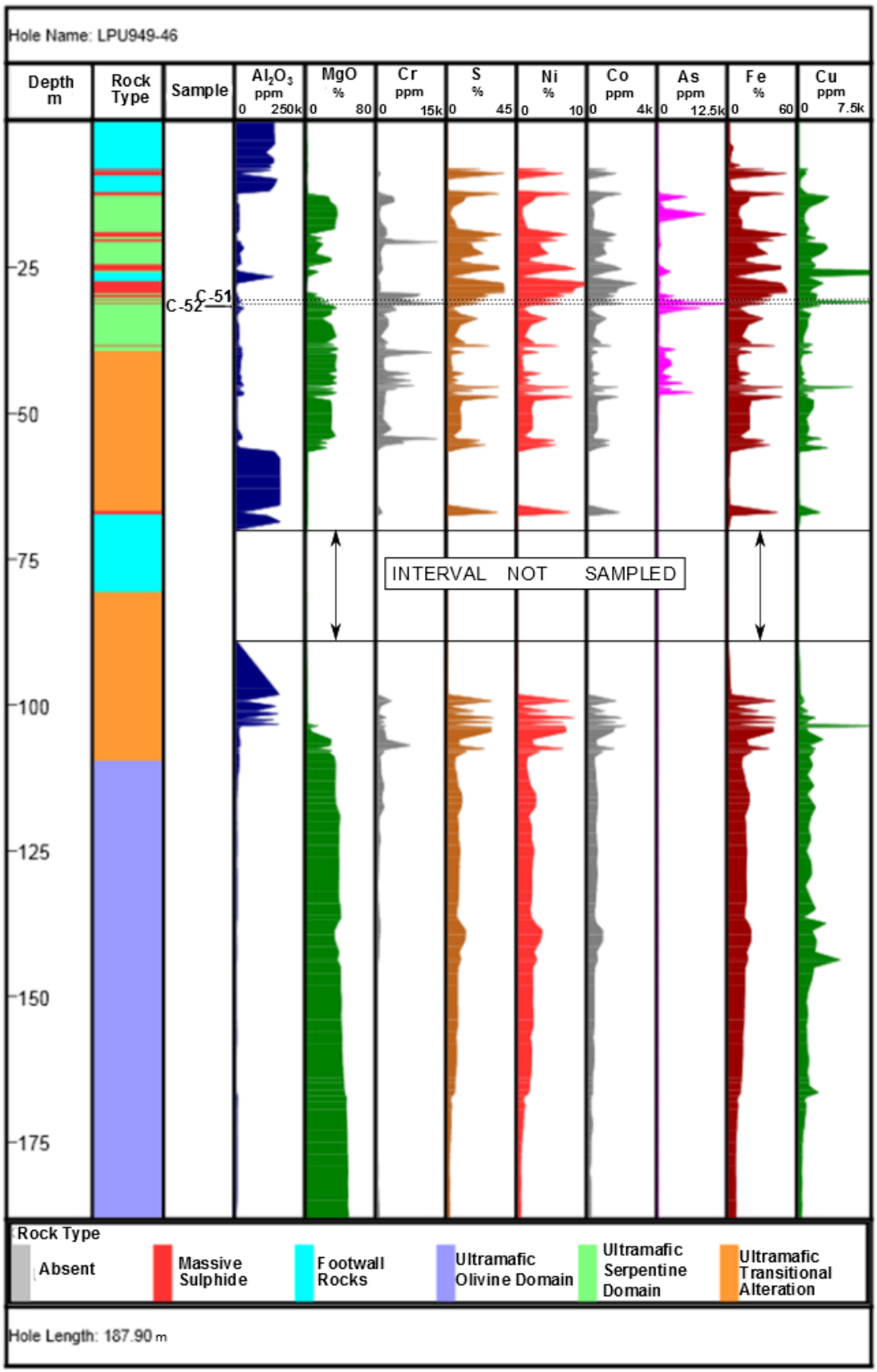

Hole Name: LPU941-29
Depth m
Rock Type
Sample
Al2O3 ppm 0 175k
MgO % 0 80
Cr ppm 0 3k
S % 0 45
Ni % 0 10
Co ppm 0 2.5k
As ppm 0 1.5k
Fe % 0 60
Cu ppm 0 7.5k
25
50
75
100
125
150
175
C-56
INTERVAL NOT SAMPLED
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 197.70 m

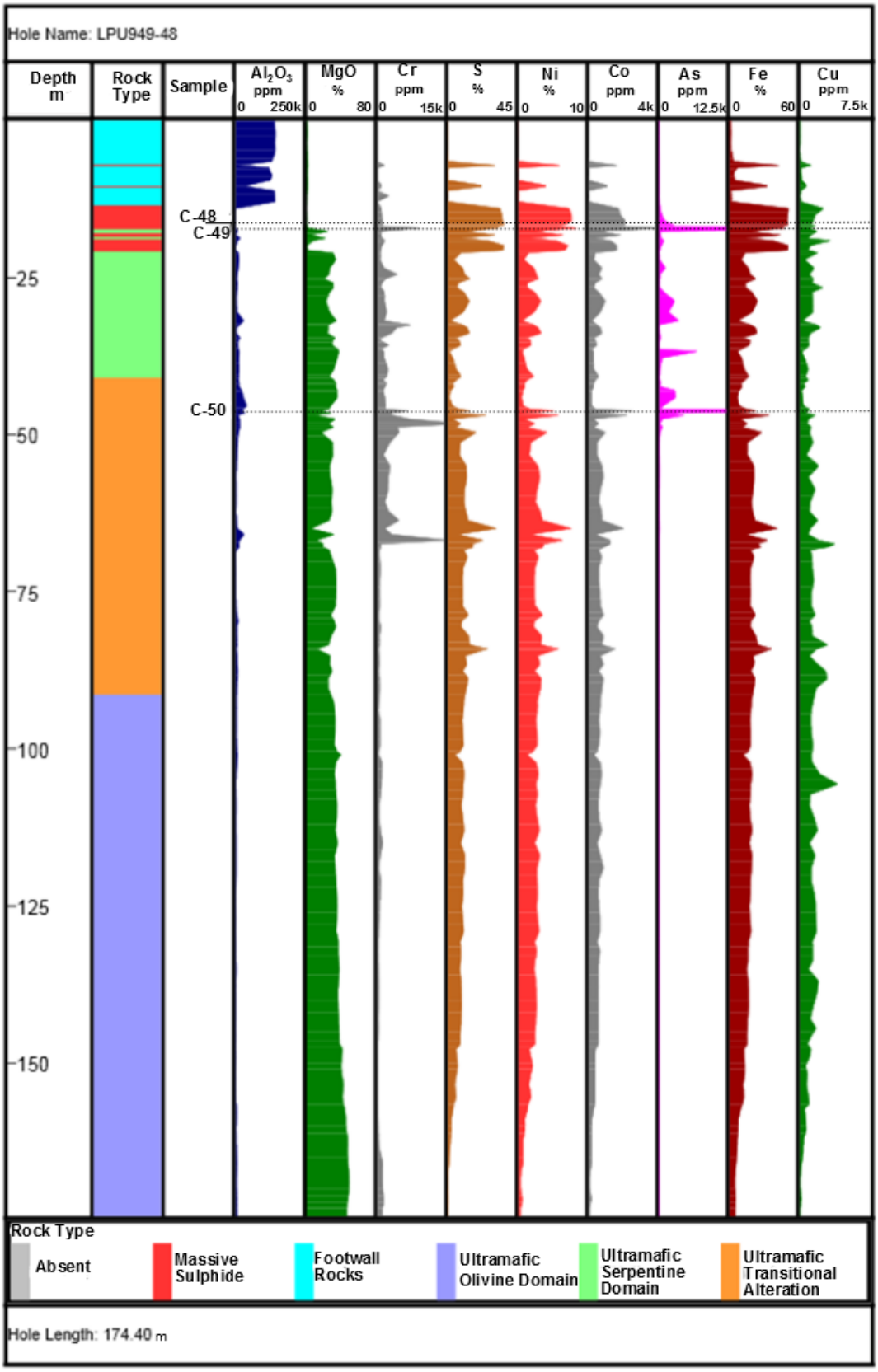

Hole Name: LPU941-33
Depth m
Rock Type
Sample
Al2O3 ppm 0 175k
MgO % 0 80
Cr ppm 0 3k
S % 0 45
Ni % 0 10
Co ppm 0 2.5k
As ppm 0 1.5k
Fe % 0 60
Cu ppm 0 7.5k
50
100
150
200
250
300
INTERVAL NOT SAMPLED
C-55
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 320.30 m

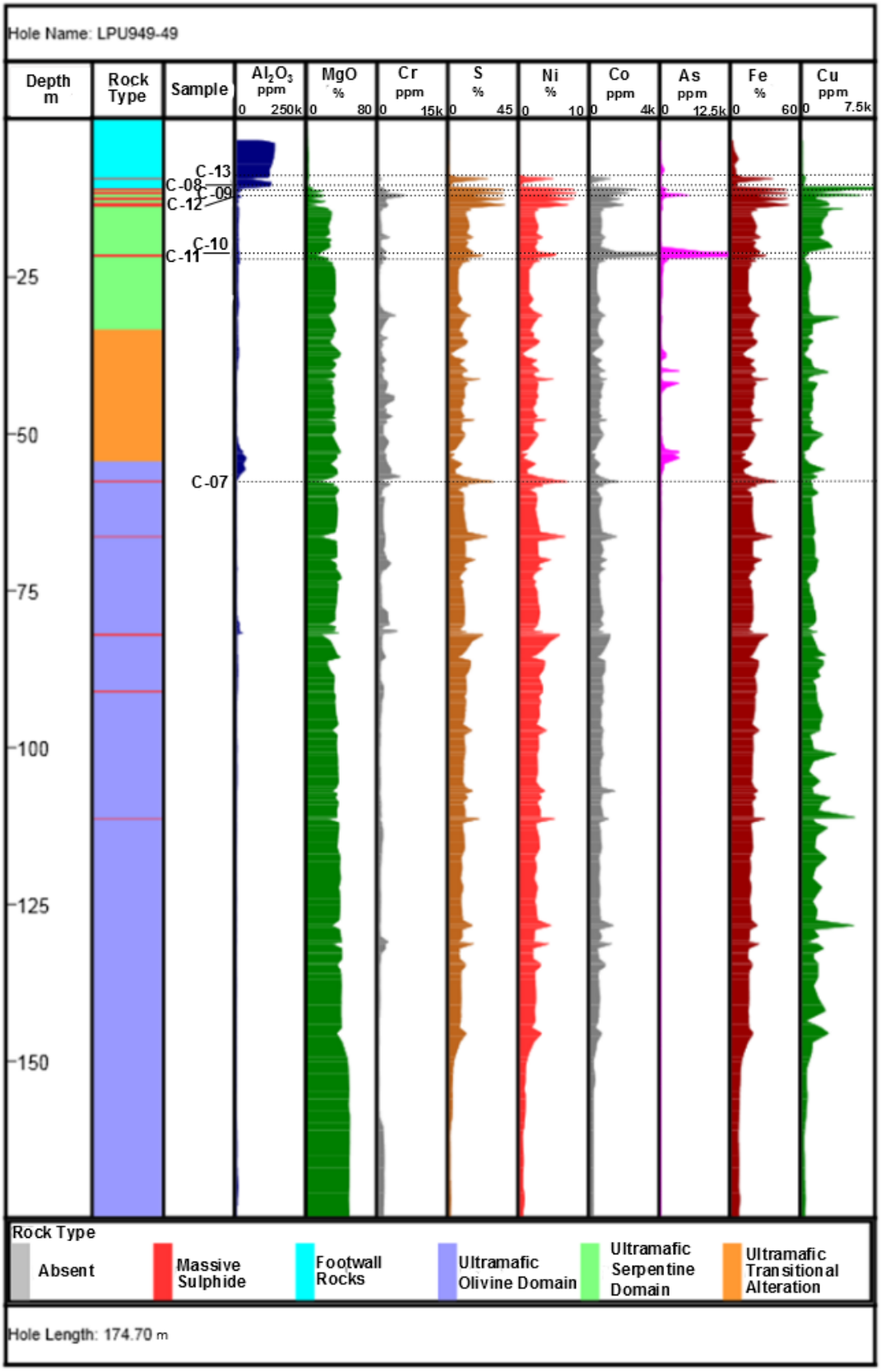

Hole Name: LPU941-49A
Depth m
Rock Type
Sample
Al2O3 ppm 0 175k
MgO % 0 80
Cr ppm 0 3k
S % 0 45
Ni % 0 10
Co ppm 0 2.5k
As ppm 0 1.5k
Fe % 0 60
Cu ppm 0 7.5k
C-57
C-58
C-59
50
100
150
200
250
INTERVAL NOT SAMPLED
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 250.40 m

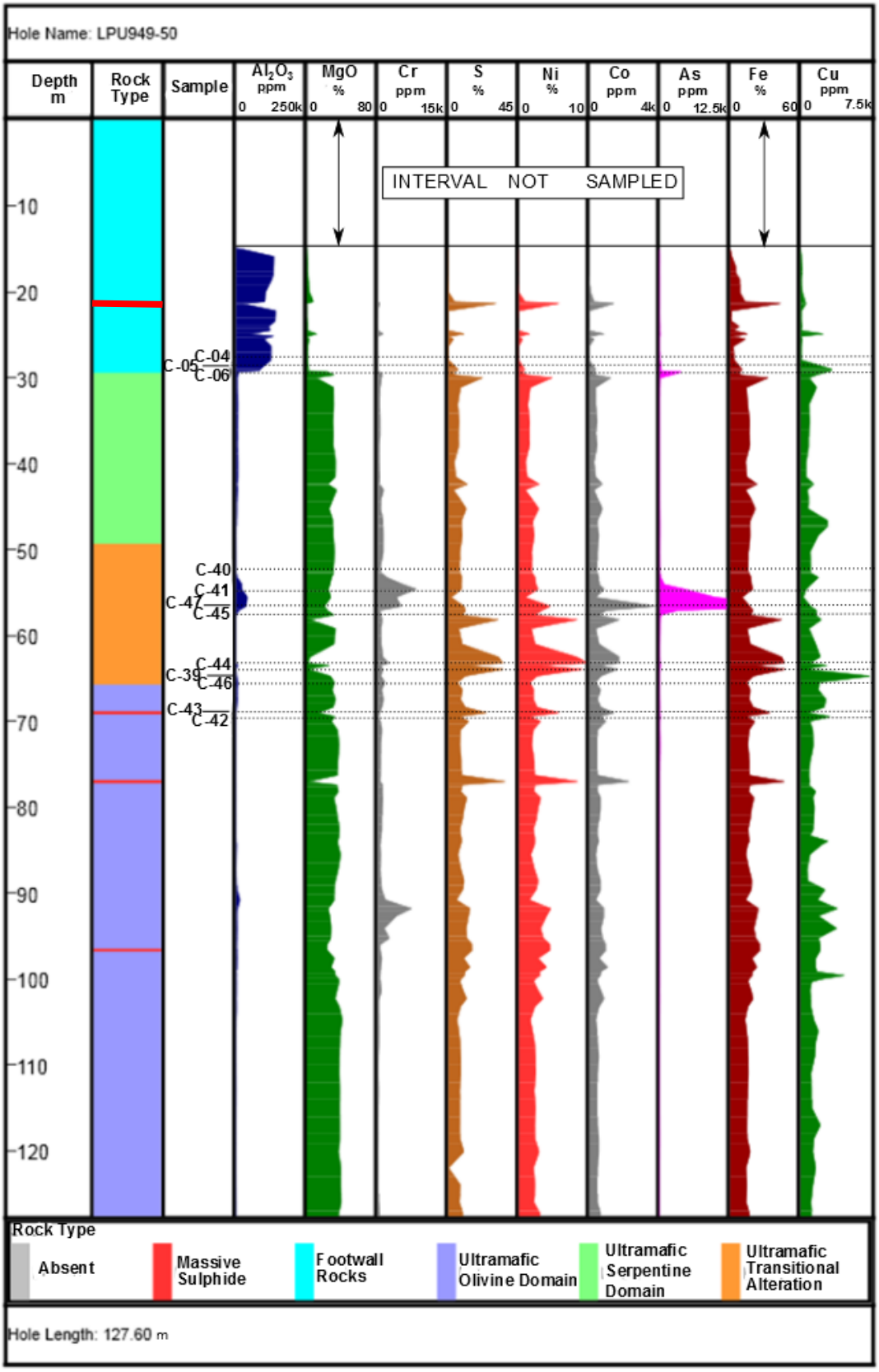

Hole Name: LPU941-90
Depth m
Rock Type
Sample
Al2O3 ppm 0 175k
MgO % 0 80
Cr ppm 0 6k
S % 0 45
Ni % 0 10
Co ppm 0 2.5k
As ppm 0 3k
Fe % 0 60
Cu ppm 0 7.5k
10
20
30
40
50
60
70
80
90
100
110
INTERVAL NOT SAMPLED
C31
C30
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 113.20 m

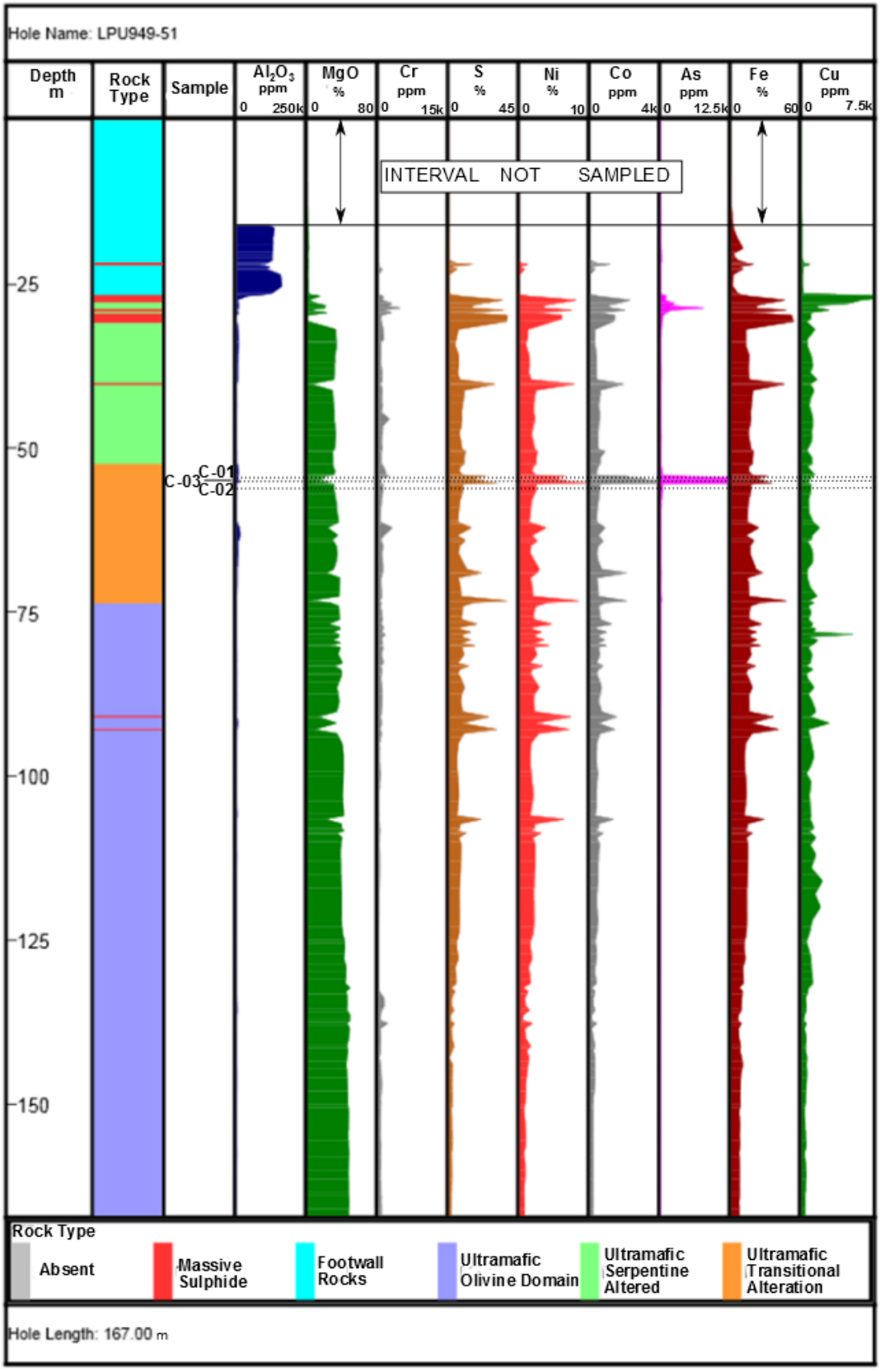

Hole Name: LPU949-44
Depth m
Rock Type
Sample
Al2O3 ppm 0 250k
MgO % 0 80
Cr ppm 0 15k
S % 0 45
Ni % 0 10
Co ppm 0 4k
As ppm 0 12.5k
Fe % 0 60
Cu ppm 0 7.5k
INTERVAL NOT SAMPLED
INTERVAL NOT SAMPLED
C-21
C-20
C-18
C-19
C-22
25
50
75
100
125
150
175
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 183.40 m

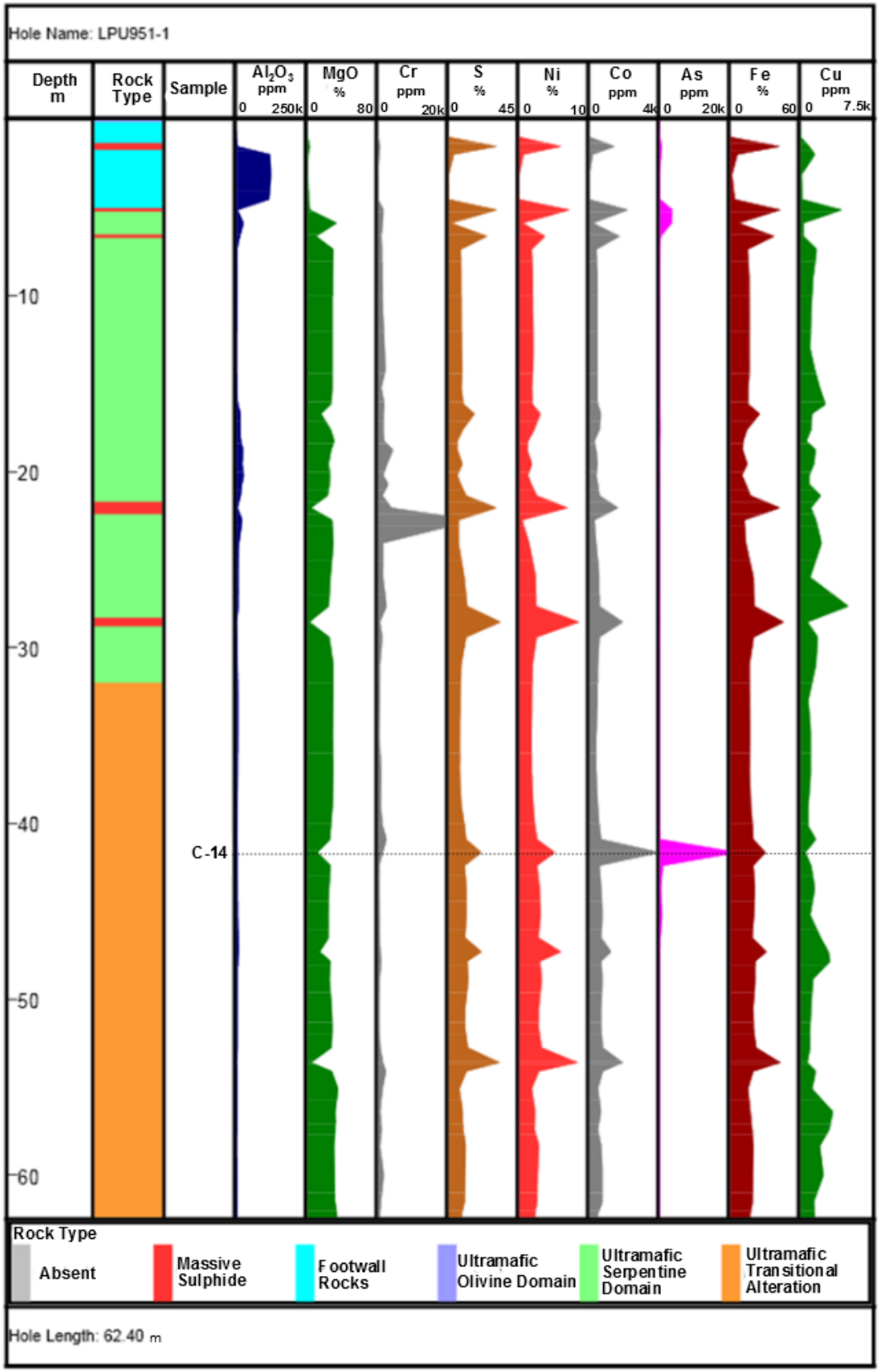

Hole Name: LPU949-46
Depth m
Rock Type
Sample
Al2O3 ppm 0 250k
MgO % 0 80
Cr ppm 0 15k
S % 0 45
Ni % 0 10
Co ppm 0 4k
As ppm 0 12.5k
Fe % 0 60
Cu ppm 0 7.5k
25
50
75
100
125
150
175
C-51
C-52
INTERVAL NOT SAMPLED
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 187.90 m

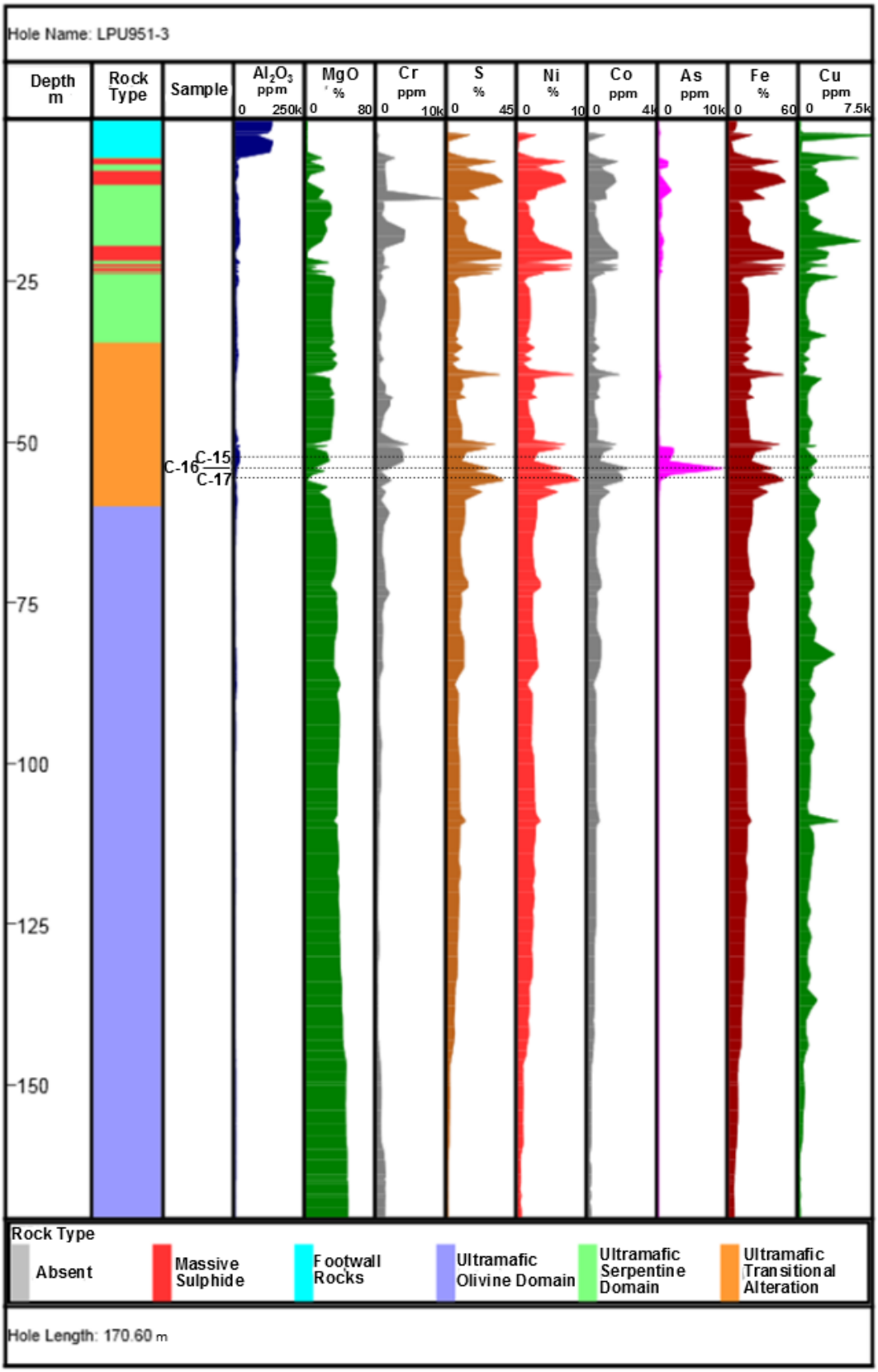

Hole Name: LPU949-48
Depth m
Rock Type
Sample
Al2O3 ppm 0 250k
MgO % 0 80
Cr ppm 0 15k
S % 0 45
Ni % 0 10
Co ppm 0 4k
As ppm 0 12.5k
Fe % 0 60
Cu ppm 0 7.5k
C-48
C-49
C-50
25
50
75
100
125
150
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 174.40 m

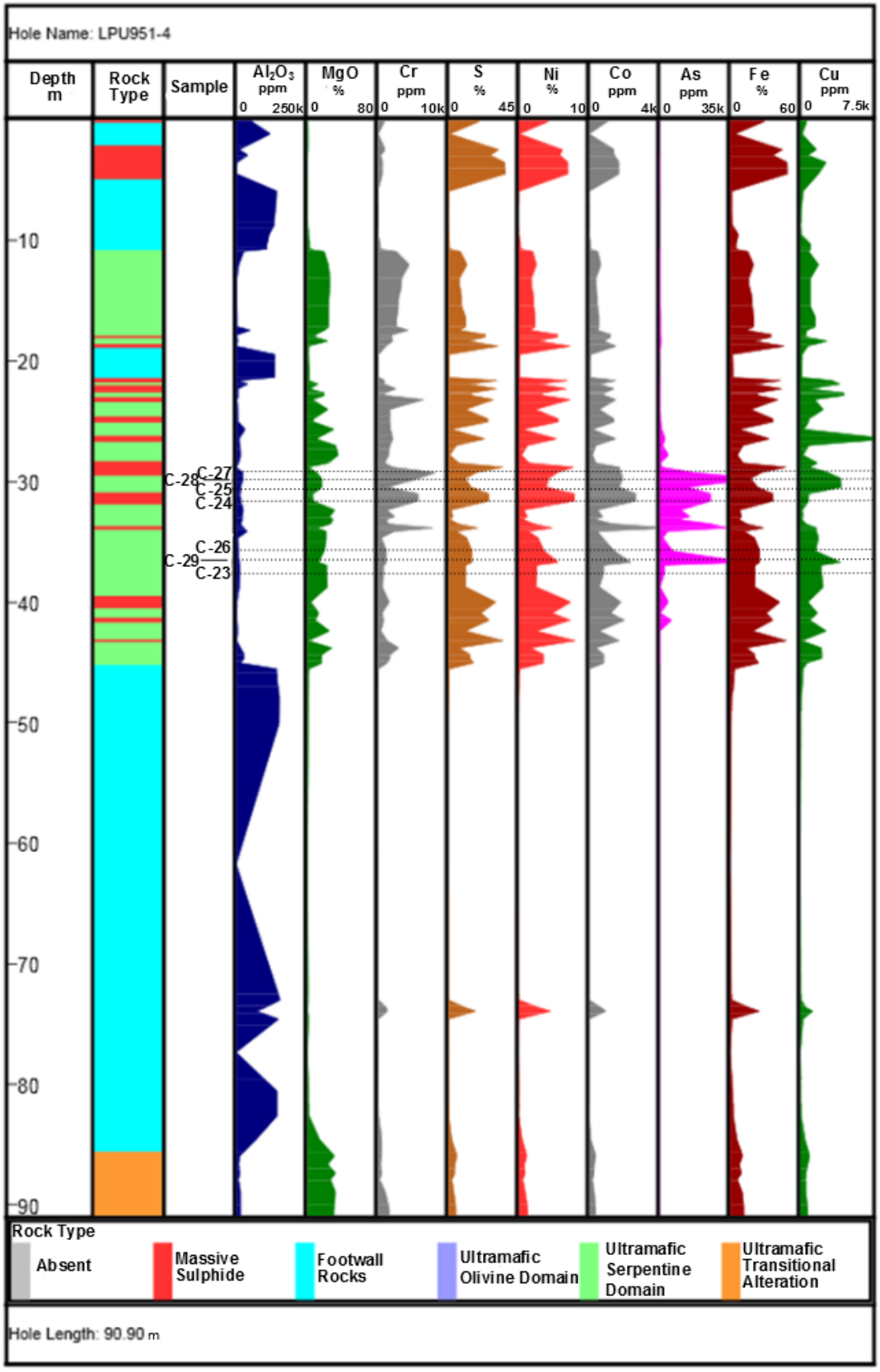

Hole Name: LPU949-49
Depth m
Rock Type
Sample
Al2O3 ppm 0 250k
MgO % 0 80
Cr ppm 0 15k
S % 0 45
Ni % 0 10
Co ppm 0 4k
As ppm 0 12.5k
Fe % 0 60
Cu ppm 0 7.5k
C-13
C-08
C-09
C-12
C-10
C-11
C-07
25
50
75
100
125
150
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 174.70 m

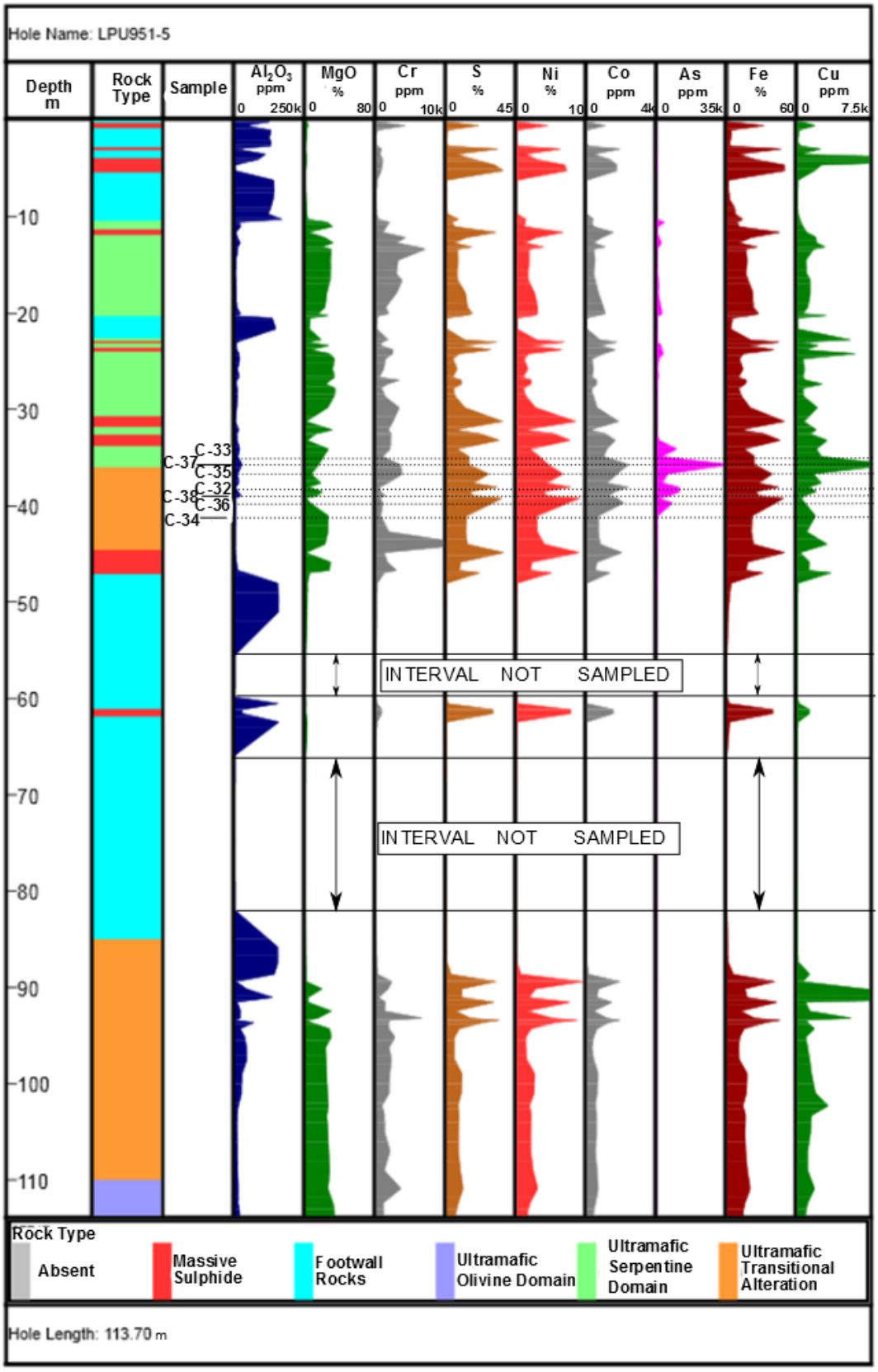

Hole Name: LPU949-50
Depth m
Rock Type
Sample
Al2O3 ppm 0 250k
MgO % 0 80
Cr ppm 0 15k
S % 0 45
Ni % 0 10
Co ppm 0 4k
As ppm 0 12.5k
Fe % 0 60
Cu ppm 0 7.5k
INTERVAL NOT SAMPLED
10
20
30
40
50
60
70
80
90
100
110
120
C-04
C-05
C-06
C-40
C-41
C-47
C-45
C-44
C-39
C-46
C-43
C-42
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 127.60 m


Hole Name: LPU949-51
Depth m
Rock Type
Sample
Al2O3 ppm 0 250k
MgO % 0 80
Cr ppm 0 15k
S % 0 45
Ni % 0 10
Co ppm 0 4k
As ppm 0 12.5k
Fe % 0 60
Cu ppm 0 7.5k
INTERVAL NOT SAMPLED
25
50
75
100
125
150
C-03
C-01
C-02
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Altered
Ultramafic Transitional Alteration
Hole Length: 167.00 m


Hole Name: LPU951-1
Depth m
Rock Type
Sample
Al2O3 ppm 0 250k
MgO % 0 80
Cr ppm 0 20k
S % 0 45
Ni % 0 10
Co ppm 0 4k
As ppm 0 20k
Fe % 0 60
Cu ppm 0 7.5k
10
20
30
40
50
60
C-14
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 62.40 m


Hole Name: LPU951-3
Depth m
Rock Type
Sample
Al2O3 ppm 0 250k
MgO % 0 80
Cr ppm 0 10k
S % 0 45
Ni % 0 10
Co ppm 0 4k
As ppm 0 10k
Fe % 0 60
Cu ppm 0 7.5k
25
50
75
100
125
150
C-16
C-15
C-17
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 170.60 m


Hole Name: LPU951-4
Depth m
Rock Type
Sample
Al2O3 ppm 0 250k
MgO % 0 80
Cr ppm 0 10k
S % 0 45
Ni % 0 10
Co ppm 0 4k
As ppm 0 35k
Fe % 0 60
Cu ppm 0 7.5k
10
20
30
40
50
60
70
80
90
C-28
C-27
C-25
C-24
C-26
C-29
C-23
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 90.90 m


Hole Name: LPU951-5
Depth m
Rock Type
Sample
Al2O3 ppm 0 250k
MgO % 0 80
Cr ppm 0 10k
S % 0 45
Ni % 0 10
Co ppm 0 4k
As ppm 0 35k
Fe % 0 60
Cu ppm 0 7.5k
10
20
30
40
50
60
70
80
90
100
110
C-33
C-37
C-35
C-32
C-38
C-36
C-34
INTERVAL NOT SAMPLED
INTERVAL NOT SAMPLED
Rock Type
Absent
Massive Sulphide
Footwall Rocks
Ultramafic Olivine Domain
Ultramafic Serpentine Domain
Ultramafic Transitional Alteration
Hole Length: 113.70 m

APPENDIX 3. Petrographic descriptions

Forty seven samples were examined by reflected-transmitted light microscopy (RTL), nine samples of the country rocks were examined by transmitted light microscopy (TL) and eight samples were studied by reflected light microscopy (RL). All conventional microscopy study was undertaken using facilities at Curtin University, Dept of Applied Geology

The following individual section descriptions include the sample id, rock description, mineralogy description by gangue (transmitted light) and ore mineral (reflected light), ore texture/parageneses and comments.

Sample Nº: C-01

Rock Description: Massive sulphide veins with minor ultramafic with matrix and disseminated sulphides and carbonate veins.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Tremolite-actinolite	7	Fine aggregates with disseminated sulphide
Talc	Tr	Bright pink alteration on the edge of the tremolite-actinolite
Calcite	3	Very fine matrix in nodular zones
Chlorite	7	Small tabular close to anthophyllites rich zones
Anthophyllite	5	Coarse, very altered and not orientated.

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	34	Main sulphide, sharp edges and with bladed texture preserved
Pentlandite	18	Fine, only seen in coarse pyrrhotite matrix
Gersdorffite	26	In disseminated, similar to pyrite however whiter and some very coarse grains (porphyroblasts)
Magnetite	Tr	Small grains , generally alteration of pyrrhotite or most like along amphiboles.

***Tr - trace**

Ore texture/paragenesis:

Brecciated massive sulphide rock sample, however the high tremolite+chlorite suggests a presence of a orthocumulate ultramafic source or secondary alteration with potential addition of Ca. Pyrrhotite and pentlandite + calcite and chlorite in veins (hydrothermal or metasomatism). Gersdorffite generally is present with actinolite-tremolite rich zones.

Comments:

Two sets of foliation present

Sample Nº: C-02

Rock Description: Serpentinised matrix and disseminated sulphide olivine-cumulate with minor carbonate alteration and micro massive sulphide veins.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Magnesite/Calcite	7	Veins and spots in serp. matrix
Serpentine	53	Main matrix with minor magnesite alteration and rare talc
Talc	3	Small masses very bright along serpentine+calcite alteration edges
Anthophyllite	Tr	Big prismatic crystals partially altered
Olivine	11	Relicts of metamorphic olivine altered to serpentine and anthophyllite

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	16	Main sulphide matrix, pale yellow, partially altered
Pentlandite	6	Cream yellow, rims and flames with pyrrhotite and rare coarse secondary grains
Gersdorffite	2	Cubic, inside pentlandite or coarse orientated with carbonates
Magnetite/ferri chromite	2	Skelectal with pentlandite rich zones, very altered

***Tr - trace**

Ore texture/paragenesis:

Typical disseminated/matrix sulphide rock sample with pyrrhotite and pentlandite in serpentine matrix and rare in veins. Small clasts of spinel (most Chromite (core) and alteration/zonation to magnetite). Also magnetite filling cracks in pyrrhotite mass, high metamorphosed rock due to re-crystallisation of secondary olivine.

Comments:

Ex-olivine-cumulate sulphide ultramafic altered by metamorphism, probably during the peak metamorphism, which is mostly characterized by the presence of secondary “bladed” olivine. Later alteration with carbonates and serpentine.

Sample Nº: C-03

Rock Description: Matrix and disseminated sulphide olivine-cumulate with massive sulphides veins, and carbonate and serpentine alteration.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
olivine	15	Relicts of metamorphic olivine altered to serpentine and anthophyllite
Serpentine	17	Main matrix with minor magnesite alteration and rare talc
talc	1	Fine, bright pink prisms in serpentine matrix
tremolite	7	Prismatic aggregates intergroup with gersdorffite
Anthophyllite	14	Big prismatic crystals partially altered
Calcite/dolomite	8	Veins and spots in serp. matrix

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	20	Main sulphide matrix, pale yellow, partially altered
Pentlandite	9	Cream yellow, rims with pyrrhotite and rare coarse secondary grains
Gersdorffite	9	Bright, idioblast mineral, coarse formed along aggregates of olivine or tremolite+carbonates

***Tr - trace**

Ore texture/paragenesis:

Bladed and coarse granular olivine with sub-parallel fractures and bright coarse Anthophyllite and less amounts of tremolite. Massive sulphides in brecciated zones and disseminated sulphides with coarse secondary gersdorffite.

Comments:

Ex olivine-cumulate sulphide ultramafic with disseminated iron rich sulphide in high metamorphism (presence of secondary olivine). Later alteration with carbonates and tremolite-actinolite with very coarse gersdorffite replacing pyrrhotite and pentlandite.

Sample Nº: C-04

Rock Description: Quartz-plagioclase-biotite schist

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
quartz	45	abundant micromosaic to 0.2mm
microcline	30	abundant micromosaic
plagioclase	10	less abundant partly clouded
hornblende	tr	partly foliated but less schistose than the biotite
biotite	15	seems to be slightly oblique to the layering, with an imbricate arrangement

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Not Present		

***Tr - trace**

Rock texture:

The sample shows coarse biotite to 0.4mm in grainsize disseminated or following foliation in micromosaic of quartz and feldspar (microcline) with probable plagioclase clearly visible only adjacent to hairline fractures with possible clays.

Comments:

No sulphide present in the sample. This sample represents metamorphosed semipelitic sediment located along a mylonitic zone.

Sample Nº: C-05

Rock Description: Felsic with sulphide veins.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Quartz	40	Fine and coarse with biotite
Muscovite	6	In fine matrix with plagioclase
Biotite	3	In coarse re-crystallised zones with quartz
Chlorite	3	Minor in mafic mineral rich side
Plagioclase	10	In fine chaotic fine texture with quartz and muscovite
Hornblende	4	Coarse with tremolite fine matrix
Ortho-pyroxene	1	Altered to Hornblende (core partially preserved)
Tremolite	8	Fine with Hornblende rich zones

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	18	Main sulphide matrix, pale yellow, partially altered
Pentlandite	3	Cream yellow, rims with pyrrhotite and rare coarse secondary grains
Pyrite	2	Coarse cubic grains
Chalcopyrite	2	Coarse very dark yellow, later crystallisation

***Tr - trace**

Ore texture:

Plagioclase + quartz micro mosaic with 0.1 to 0.4mm + irregular disseminated biotite + muscovite +sericite rich zones. Coarse quartz blasts with biotite (one half of the sample). The other half is composed by coarse pyroxene (ortho) + tremolite + hornblende + plagioclase with clac-silicate alterations textures. And small sulphide veins

Comments:

Remobilized sulphide in shear zones with quartz+biotite alterations (country rock). Possibly metasediments with calc-silicate alterations.

Sample Nº: C-06

Rock Description: Ex- orthocumulate ultramafic rock with disseminated sulphide and later carbonate alteration.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Tremolite	49	Main mineral on half of the section, small 10 micros grains, partially round and some areas rimming Anthophyllite and in 2 sets of foliation very evident, with the first with kinks and micro folds
Olivine	Tr	Rare small core preserved in serpentine rich areas
Serpentine	5	Represents the main mineral in to the other part of the section,
Calcite	5	Filing young fractures
Anthophyllite	25	Big crystals very altered
chlorite	2	In serp rich areas

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	7	Main sulphide matrix, pale yellow, partially altered and in brecciated zone
Pentlandite	2	Cream yellow, rims with pyrrhotite and in flame textures
Gersdorffite	Tr	Small present in all three zones, mostly round, white and rare coarse in the tremolite rich zone
Magnetite	5	Common along contact zones (serp/tremolite with massive sulphide area) and filling small cracks in serp rich zone.

***Tr - trace**

Ore texture/paragenesis: Brecciated zone (shear in central part) with pyrrhotite and clasts of serp+tremlite. Very small and rare pentlandite (flame like texture). Strong and pervasive alteration of magnetite from contact zone. Gersdorffite tends to form along with tremolite granoblasts.

Comments: Altered olivine-orthocumulate rock with disseminated sulphide. 2 clear metamorphic phases (probably the first with tremolite and second with carbonate+chlorite). Magnetite is mostly alteration from olivine in serpentine rich areas.

Sample Nº: C-07

Rock Description: Massive sulphide with clasts of gangue

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
No classified	24	Reflective sample – no gangue characterization

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	35	Very altered (purple colours) veins and flame with pentlandite preserved
Pentlandite	17	Coarse yellow/cream, fractured and partially altered
Pyrite	21	White inclusions in pyrrhotite matrix
Magnetite	3	Generally euhedral crystals, isotropic, and sometimes round in pyrrhotite matrix or in micro veins with pyrrhotite/pentlandite
Violarite	Tr	Only two grains preserved, very purple in extremely altered pentlandite

***Tr - trace**

Ore texture/paragenesis:

Massive sulphide, no primary texture preserved (some MSS flame like texture preserved, after peak of metamorphism?), rare remobilization and only secondary alteration due to oxidation (magnetite and pyrite). Mostly pyrrhotite rich matrix with pentlandite disseminated or in flames textures (exsolution).

Comments:

Typical massive sulphide with pyrrhotite rich matrix with pentlandite and some oxidation.

Sample Nº: C-08

Rock Description: Contact of disseminated ultramafic +massive sulphide and metasediments

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Olivine	7	Neoblastic, coarse and replaced
Chlorite and talc	9	Mostly around olivine and alteration front
Tremolite	17	Fan like, very coarse and euhedral, mostly disseminated
Calcite	3	Spots and clasts, along micro veins
Biotite Biotite and muscovite	5	Associated with chlorite along the contact with felsic rocks and margin the massive sulphide veins. Secondary type is on the felsic rocks, very thick and oriented (2 sets of foliation and crenulation) intergrown with muscovite
Hornblende	5	Rare prismatic euhedral grains along contact zone
Quartz	10	Micromosaic
Plagioclase	5	Micromosaic

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	19	Main sulphide matrix, pale yellow, partially altered by chalcopyrite and pyrite
Pentlandite	6	Cream yellow, orthogonal and coarse
Pyrite	10	Coarse cubic grains, isotropic and alteration from Pyrrhotite
Chalcopyrite	Tr	Coarse very dark yellow, later crystallisation
Gersdorffite	4	Small generally round and minor amount of porphyroblasts disseminated in calcite matrix sometimes replacing pyrrhotite
Ferri-chromite /magnetite	Tr	Skelectal + and rare core preserved in cubic and hexagonal minerals

***Tr - trace**

Ore texture/paragenesis:

Two sides of rocks, one on the felsic shows coarse biotite to 0.2mm in grainsize disseminated or following foliation in micromosaic of quartz and feldspar (microcline) with probable plagioclase clearly visible only adjacent to hairline fractures with possible clays.

On the ultramafic there is no evidence of primary textures. Some evidence preserved of secondary textures of re-crystallisation of mafic minerals into amphibole series and addition of Ca (hornblende and tremolite).

Comments:

Very clear chalcopyrite alterations.

Sample Nº: C-09

Rock Description: Massive sulphide with minor clasts of gangue.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
No classified	10	Reflective sample – no gangue characterization

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	51	Brown or tint with minor purple oxidized zones areas (anhedral)
Pentlandite	28	Coarse yellow/cream, fractured and partially altered along cracks with round sub-euhedral.
Pyrite	10	Cubic white mineral with high reflectance with no inclusions
Chalcopyrite	1	Coarse very dark yellow, later crystallisation associate with pyrite
Magnetite	Tr	Generally euhedral crystals, isotropic, and sometimes round in pyrrhotite matrix or in micro veins with pyrrhotite/pentlandite

***Tr - trace**

Ore texture/paragenesis:

Presence of massive sulphide with some exsolution of pyrrhotite/pentlandite and euhedral magnetite). Rare remobilization and only secondary alteration due to oxidation, marked by the pyrite and minor magnetite.

Comments:

Slight foliated, pyrite rich and very altered in some pyrrhotite rich zones.

Sample Nº: C-10

Rock Description: Massive carbonate rock with disseminated sulphides and clasts of ultramafic.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Calcite	26	Rhombohedral and fine matrix with disseminated sulphides and serpentine
Dolomite	3	Similar to calcite with higher birefringence
Serpentine	17	Aggregates with calcite
chlorite	Tr	Rare alterations along edges of serpentine

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	15	Small grains disseminated in calcite and serpentine matrix and with edges altered
Pentlandite	15	Cream yellow fractures in pyrrhotite rich zones
Gersdorffite	14	Small generally cubic disseminated in calcite matrix sometimes replacing pyrrhotite
Ferri-chromite /magnetite	Tr	Skelectal + some are small cubic replaced on the border by light grey magnetite

***Tr - trace**

Ore texture/paragenesis:

Chaotic aggregate of calcite and serpentine, very fine and small disseminated grains of sulphide + ferri-chromite. Evidences of replacement of serpentine by carbonates (calcites), all sulphides, expect gersdorffite have alteration on edges. Gersdorffite is the only re-crystallised with carbonate event.

Comments:

Metasomatic rock

Sample Nº: C-11

Rock Description: Matrix and disseminated sulphide olivine-cumulate with carbonate alteration and minor massive sulphide veins.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Calcite	10	Veins and spots in serp. matrix
Serpentine	18	Main matrix with minor altered olivine remaining (lizardite)
Talc	Tr	Small masses very bright along serpentine+calcite alteration edges
Tremolite	3	Small aggregates replaced by calcite and/or lizardite
Olivine	Tr	Relicts of metamorphic olivine altered to serpentine

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	56	Main sulphide matrix, pale yellow or brown
Pentlandite	8	Coarse with spinel (chromite/magnetite) aggregates
Gersdorffite	2	Small crystals located along calcite alterations edges and in veins
Magnetite/ferri chromite	3	With pentlandite rich zones, very altered

***Tr - trace**

Ore texture/paragenesis:

Matrix and heavily disseminated sulphide rock sample with pyrrhotite and pentlandite in serpentine matrix and minor veins. Small aggregates of spinel (most chromite (core) and alteration/zonation to magnetite) in association with pentlandite. Also magnetite filling cracks in pyrrhotite mass, high metamorphosed rock due to re-crystallisation of secondary olivine. Gersdorffite is located with calcite and it is the result of alteration of mainly pentlandite.

Comments:

Ex olivine-sulphide cumulate with high metamorphism alteration and rich in spinel (chromite). Later alteration with carbonates and coarse gersdorffite.

Sample Nº: C-12

Rock Description: Serpentinised matrix and disseminated sulphide olivine-cumulate carbonate alteration and minor massive sulphide veins.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	45	Main matrix with bladed structures remaining (lizardite)
Calcite	4	Small rhombohedral and fine matrix with disseminated sulphides and serpentine
Chlorite	8	Small tabular close to coarse rich zones of lizardite
Talc	1	Rare masses of very bright minerals along serpentine+calcite alteration edges

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	26	Main sulphide matrix, pale yellow or brown
Pentlandite	13	Cream yellow, rims and flames with pyrrhotite and rare coarse secondary grains
Magnetite/ferri chromite	1	Skelectal with pentlandite rich zones, very altered and rare chalcopyrite
Gersdorffite	2	Small crystals located along calcite alterations edges and in veins. Minor small gersdorffite in inter grown with spinel is present.
chalcopyrite	Tr	In high straighten zones, generally with talc + calcite rich zones

***Tr - trace**

Ore texture/paragenesis:

Disseminated sulphide rock sample with pyrrhotite and pentlandite in serpentine matrix and minor veins and bladed texture preserved. Typical olivine-cumulate ultramafic with relict phantoms of olivine replaced by lizardite . Primary exsolution of pyrrhotite and pentlandite. Skelectal and small aggregates of spinel (most Chromite (core) and alteration/zonation to magnetite) with pentlandite. Also magnetite filling cracks in pyrrhotite mass, high metamorphosed rock due to re-crystallisation of secondary olivine. Gersdorffite is located with calcite and it is the result of alteration of pyrrhotite and pentlandite.

Comments:

Ex olivine-cumulate with sulphides and high metamorphism and rich in spinel (chromite). Later alteration with carbonates and coarse gersdorffite. Presence of small gersdorffite in intergrowth with spinel is present.

Sample Nº: C-13

Rock Description: Quartz-plagioclase-biotite schist

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
quartz	70	abundant micromosaic to 0.2mm
microcline	2	less abundant partly clouded
plagioclase	14	abundant micromosaic
hornblende	Tr	partly foliated but less schistose than the biotite
biotite	14	seems to be slightly oblique to the layering, with an imbricate arrangement

***Tr - trace**

Rock texture:

This sample represents a more quartz rich micromosaic, richer and Ca and biotite along shears and 2 sets of foliation.

Comments:

No sulphide present in the sample. This sample represents metamorphosed psammitic to minor semipelitic sediment.

Sample Nº: C-14

Rock Description: Matrix and disseminated sulphide olivine-cumulate with intense carbonate alteration and sulphide re-crystallisation along shears (visible naked eye gersdorffite).

Mineralogy: Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	7	Matrix with minor
Calcite/dolomite	9	Veinlets or along alteration edges and spots in serp. matrix
talc	Tr	Fine, bright pink prisms in serpentine matrix
tremolite	Tr	Prismatic aggregates intergroup with gersdorffite
Anthophyllite	16	Big parts of the original prismatic crystals
olivine	Tr	Relicts of metamorphic olivine altered to serpentine and anthophyllite

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Gersdorffite	32	Main sulphide, very bright, coarse formed replacing pyrrhotite and pentlandite along shear zones with carbonates generally in porphyroblasts mineral types and rare round possible primary droplet preserved.
Pyrrhotite	20	pale yellow replaced by gersdorffite
Pentlandite	16	Cream yellow, rims with pyrrhotite and rare coarse secondary grains
Magnetite	1	Grey masses in shear zones replacing pyrrhotite.
chalcopyrite	Tr	Rare and generally with talc + calcite rich zones

***Tr - trace**

Ore texture/paragenesis: Ultramafic with disseminated sulphide in net texture with pyrrhotite + pentlandite. Coarse anthophyllite crystals and intense alteration of carbonates (Metasomatism) resulting in the alteration of neoblasts of olivine. Intense arsenic alteration and re-crystallisation of gersdorffite with shear zone of 2.5cm with veins of gersdorffite and edges of calcite (inclusions of pyrrhotite + pentlandite, spinel, lizardite and anthophyllite.

Comments: Ex olivine-sulphide cumulate which was affected by high metamorphism (presence of secondary olivine). Presence of arsenic-bearing mineral associated with later alteration of carbonates (pure mass of coarse gersdorffite replacing pyrrhotite and pentlandite).

Sample Nº: C-15

Rock Description: Olivine-tremolite-chlorite schist with carbonate alteration and minor massive sulphide veins.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Olivine	45	Relicts of metamorphic bladed olivine altered to serpentine and anthophyllite
Serpentine	14	Alteration matrix with remaining of olivine
Dolomite	3	Veins and spots in serpentine alteration zones
tremolite	10	Prismatic aggregates intergroup with gersdorffite
Talc	1	Small masses very bright along serpentine+calcite alteration edges
Chlorite	2	Coarse re-crystallised zones (clinochlore)

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	14	Main sulphide matrix, pale yellow, partially altered
Pentlandite	7	Cream yellow, very coarse with rims and flames with pyrrhotite and rare coarse secondary grains
Gersdorffite	4	Small grains in brecciated zones or inside pyrrhotite grains
Magnetite	Tr	Rimming pyrrhotite or pentlandite rich zones, very altered

***Tr - trace**

Ore texture/paragenesis:

Some olivine from retro-metamorphism (neoblasts). Gangue is mostly composed of olivine and minor tremolite with chlorite filling the gaps with a later serpentine alteration. Sulphide is mostly in massive zones (remobilized along shears) with exsolution of pyrrhotite and pentlandite. .Dolomite alterations and presence of arsenic mineral along carbonatization zones.

Comments:

Ex orthocumulate komatiite (olivine-enriched cumulate B-zone) which was affected by high metamorphism (presence of secondary olivine). Later alteration with carbonates and crystallisation of gersdorffite and serpentinisation.

Sample Nº: C-16

Rock Description: Massive sulphide veins with clasts of ultramafic with disseminated sulphides with carbonate alteration.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Olivine	10	Residual in mosaic very altered
Serpentine	11	Main matrix with minor olivine core preserved alteration and rare talc
Talc	Tr	Fine, bright pink prisms in serpentine matrix
Tremolite	3	Prismatic aggregates in fan like, very common
Anthophyllite	3	Big prismatic crystals partially altered
Calcite/dolomite	5	Veins and coarse spots in serpentine matrix

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	43	Main sulphide matrix, pale yellow, partially altered
Pentlandite	18	Cream yellow, very coarse with secondary texture.
Gersdorffite	7	Small inclusions in pyrrhotite and pentlandite or coarser formed along aggregates of tremolite+carbonates. Sometimes round or cubic
Magnetite	Tr	Filling cracks in pyrrhotite or pentlandite rich zones
Millerite	Tr	Traces, small yellow grains rimming pentlandite

***Tr - trace**

Ore texture/paragenesis:

Massive sulphide, with no primary texture preserved, strongly foliated and with brecciated zones with gersdorffite present. Magnetite rimming gangue (possible olivine) and clasts of ultramafic rocks.

Comments:

Strongly foliated, pyrite rich and very altered in some pyrrhotite rich zones and possible hydrothermal and oxidation alterations (altered pyrrhotite and re-crystallisation of gersdorffite).

Sample Nº: C-17

Rock Description: Massive sulphide with inclusions of gangue minerals.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
No classified	30	Reflective sample – no Gangue characterization

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	39	Brown or tint highly altered with purple colour in oxidized zones areas. Minor parts brecciated.
Pentlandite	17	Coarse yellow/cream, fractured and partially altered along cracks with round sub-euhedral.
Gersdorffite	1	Minor grains in Gangue brecciated zone
Pyrite	9	Round to elliptical shape, white no scratches on surface (very hard)
Chalcopyrite	Tr	Inter-grown with pentlandite in aggregate zone
Magnetite/chromite	3	Light grey with zonation and crystals with hexagonal shape

***Tr - trace**

Ore texture/paragenesis:

Massive sulphide, with no primary texture preserved, strongly foliated and with brecciated zones with gersdorffite present. Magnetite rimming gangue (possible olivine).

Comments:

Strongly foliated, pyrite rich and very altered in some pyrrhotite rich zones and possible hydrothermal and oxidation alterations (altered pyrrhotite and re-crystallisation of gersdorffite).

Sample Nº: C-18

Rock Description: Brecciated massive sulphide chromite-rich with ultramafic clasts.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	14	Main matrix with bladed structures remaining (lizardite)
Tremolite	Tr	Prismatic aggregates in fan like, very common
Chlorite	5	Small tabular close to coarse rich zones of lizardite
Talc	Tr	Rare masses of very bright minerals along serpentine alteration edges

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	45	Main sulphide matrix, pale yellow or brown
Pentlandite	19	Cream yellow, rims and flames with pyrrhotite and rare coarse secondary grains
Chromite	10	Extremely coarse euhedral grains edges altered to magnetite (one grain with 0.7 cm)
Gersdorffite	7	Coarse formed replacing pyrrhotite and pentlandite along shear zones with carbonates generally in porphyroblasts mineral types and rare round possible primary droplet preserved.

***Tr - trace**

Ore texture/paragenesis:

Massive sulphide with remaining of serpentine and extremely coarse spinel (chromite) with magnetite rimming.

Comments:

Strongly foliated, pyrite rich and very altered in some pyrrhotite rich zones and possible hydrothermal and oxidation alterations (altered pyrrhotite and re-crystallisation of gersdorffite), evidences of high amount of coarse chromite, minor silicate clasts mostly due to metamorphism and shear zones.

Sample Nº: C-19

Rock Description: Brecciated tremolite-chlorite schist with micro massive veins of sulphides.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Tremolite	10	Small prismatic aggregates or rare in fan like, very common forming veins
Chlorite	3	Filling matrix in tremolite rich zones
Serpentine	5	In veinlets around altered olivines core
Talc	Tr	Fine, bright pink prisms in serpentine matrix
Olivine	Tr	Residual neoblasts (metamorphic) with brown/green cleavages
Calcite/dolomite	2	Veins and coarse spots in serpentine matrix

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	65	Main sulphide matrix, pale yellow, partially altered
Pentlandite	14	Cream yellow, very coarse with secondary texture.
Chalcopyrite	1	Inter-grown with pentlandite in aggregate zone

***Tr - trace**

Ore texture/paragenesis:

Some olivine from retro-metamorphism (neoblasts). Gangue is mostly composed of tremolite with chlorite filling the gaps. Sulphide is mostly in massive zones (remobilized along shears) with exsolution of pyrrhotite and pentlandite and rare alterations of chalcopyrite.

Comments:

Ex spinifex textured A zone altered by high metamorphism and later alteration with carbonates (metasomatism) with very coarse gersdorffite associated with tremolite.

Sample Nº: C-20

Rock Description: Brecciated massive sulphide chromite-rich with ultramafic clasts.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Tremolite	9	Coarse prismatic aggregates or rare in fan like, very common forming veins
Chlorite	2	Filling matrix in tremolite rich zones
Serpentine	3	In veinlets around altered olivine core
Biotite	1	Rare mostly along hornblende rich bands
Hornblende	2	Coarse grains in bands
Calcite/dolomite	3	Small aggregates surrounding tremolites rich zones

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	47	Main sulphide matrix, pale yellow, partially altered
Pentlandite	17	Cream yellow, very coarse with secondary texture.
Gersdorffite	11	Many types, small or coarse formed replacing pyrrhotite and pentlandite along shear zones with tremolites and carbonates
Chromite	5	Extremely coarse euhedral grains edges altered to magnetite with inclusions of sulphides.
Chalcopyrite	Tr	Inter-grown with pentlandite in aggregate zone

***Tr - trace**

Ore texture/paragenesis:

Massive sulphide with remaining of serpentine and extremely coarse spinel (chromite) with magnetite rimming and also rich in gersdorffite in coarse tremolite rich zones and minor biotite and hornblende. Carbonates are replacing sulphides and serpentines. Pentlandite is very coarse which suggests high secondary re-crystallisation by peak of metamorphism.

Comments:

Strongly foliated, pyrite rich and very altered in some pyrrhotite rich zones and possible hydrothermal and oxidation alterations (altered pyrrhotite and re-crystallisation of gersdorffite), evidences of high amount of coarse chromite, minor silicate clasts mostly due to metamorphism and shear zones

Sample Nº: C-21

Rock Description: Massive sulphide with minor clasts of gangue.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
No classified	3	Reflective sample – no Gangue characterization

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	67	Brown or tint with minor purple oxidized zones areas
Pentlandite	23	Coarse yellow/cream, fractured and partially altered along cracks with round to sub-euhedral crystals.
Gersdorffite	7	Round and small inclusions in pyrrhotite and pentlandite. Some rimming of cobaltite
Chalcopyrite	Tr	Coarse very dark yellow, later crystallisation associate with pyrite
Magnetite	Tr	Filling cracks in pyrrhotite matrix or in micro veins with pyrrhotite/pentlandite

***Tr - trace**

Ore texture/paragenesis:

Massive sulphide, with no primary texture preserved, strongly foliated and with brecciated zones with gersdorffite present. Magnetite is rare and it is mostly filling cracks. Remobilization and only secondary alteration due to oxidation. Mostly pyrrhotite rich matrix with pentlandite disseminated or in flames like textures (exsolution)

Comments:

Strongly foliated, pyrite rich and very altered in some pyrrhotite rich zones and possible hydrothermal and oxidation alterations (altered pyrrhotite and re-crystallisation of gersdorffite and cobaltite).

Sample Nº: C-22

Rock Description: Pyroxene with tremolite-Actinolite rich ultramafic with micro veins of massive sulphides filling fractures/shears.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Tremolite	24	Small prismatic aggregates or rare in fan like, very common forming veins
Chlorite	Tr	Rare along tremolite rich zones
Serpentine	5	In veinlets around altered olivine core
Talc	Tr	Fine, bright pink prisms in serpentine matrix
Clinopyroxene	44	Colourless mineral, sharp contour and prismatic
Calcite/dolomite	7	Veins and coarse spots in serpentine matrix

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	14	Main sulphide matrix, pale yellow, partially altered
Pentlandite	5	Cream yellow, very coarse with secondary texture.
Chalcopyrite	1	Inter-grown with pentlandite in aggregate zone

***Tr - trace**

Ore texture/paragenesis:

Rock is located along the altered contact of PUC and felsic nose. It is mostly composed of pyrrhotite and pentlandite with rare chalcopyrite along veins, of which have some disseminated ultramafic clasts.

Comments:

Sample was taken from contact between ultramafic complex and country rocks (felsic nose). No evidence of arsenic-bearing minerals inside country rock. Probably an spinifex textured A zone partially altered by high metamorphism and later alteration with carbonates (metasomatism) with very coarse gersdorffite associated with tremolite.

Sample Nº: C-23

Rock Description: Rock is brecciated with green clasts (brecciated olivine-tremolite-chlorite schist with micro massive veins of sulphides) however sample was concentrated on the massive sulphide vein with high amounts of chromite (polished block).

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
No classified	4	Reflective sample – no Gangue characterization

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	55	Brown or tint highly altered with purple colour in oxidized zones areas. Minor parts brecciated.
Pentlandite	27	Coarse yellow/cream, fractured and partially altered along cracks with round sub-euhedral.
Gersdorffite	8	In chromite rich areas, all sizes and coarser along shear zones with tremolite and carbonates
Chalcopyrite	Tr	Inter-grown with pentlandite in aggregate zone
Magnetite/chromite	6	Light grey with zonation and crystals with hexagonal shape

***Tr - trace**

Ore texture/paragenesis:

Massive sulphide, with no primary texture preserved, strongly foliated and with brecciated zones with gersdorffite present. Sample is chromite rich and altered to magnetite (rimming). Disseminated sulphide areas in gangue (possible serpentine)

Comments:

Strongly foliated, gersdorffite rich and very altered in some pyrrhotite rich zones and possible hydrothermal alterations (altered pyrrhotite and pentlandite with re-crystallisation of gersdorffite).

Sample Nº: C-24

Rock Description: Brecciated massive sulphide with ultramafic clasts.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Tremolite	15	Small prismatic aggregates or rare in fan like
Chlorite	Tr	Filling matrix in tremolite rich zones
Serpentine	20	Main silicate, matrix rich, fine
Phlogopite	Tr	Residual neoblasts (metamorphic) with brown/green cleavages
Calcite/dolomite	8	Patchy and sometimes in block (coarse areas), re-crystallised and spotted

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	35	**Textural features of mineral**
Pentlandite	10	Main sulphide matrix, pale yellow, partially altered
Gersdorffite	7	Many types, small or coarse formed replacing pyrrhotite and pentlandite with tremolites and carbonates
Ferri-Chromite	5	Small, sub-euhedral grains (rare) mostly skeletal

***Tr - trace**

Ore texture/paragenesis:

Massive sulphide, with no primary texture preserved, strongly foliated and with brecciated zones with gersdorffite present and gersdorffite is very coarse and it is a result of alteration (generally along tremolite rich veins) or extremely rare inclusions.

Comments:

Strongly foliated, pyrite rich and very altered in some pyrrhotite rich zones and possible hydrothermal and oxidation alterations (altered pyrrhotite and re-crystallisation of gersdorffite and cobaltite).

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Sample Nº: C-25

Rock Description: Olivine-tremolite-chlorite rock with micro massive veins of sulphides and minor talc.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
olivine	15	Relicts of metamorphic olivine altered to serpentine and anthophyllite
Serpentine	17	Main matrix with minor magnesite alteration and rare talc
talc	1	Fine, bright pink prisms in serpentine matrix
tremolite	7	Prismatic aggregates intergroup with gersdorffite
Anthophyllite	14	Big prismatic crystals partially altered

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	34	Main sulphide matrix (disseminated) , pale yellow, partially altered.
Pentlandite	18	Cream yellow, rims and flames with pyrrhotite and rare coarse secondary grains
Gersdorffite	26	Formed replacing pyrrhotite and pentlandite with tremolites
Magnetite	Tr	Skelectal with pentlandite rich zones, very altered

***Tr - trace**

Ore texture/paragenesis:

Bladed and coarse granular olivine with sub-parallel fractures and bright coarse anthophyllite and some chaotic aggregate of tremolite or in fan-like and garbenschiefer bundles with 3 to 5mm. Massive sulphides in brecciated zones and disseminated sulphide with coarse secondary gersdorffite

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Comments:

Olivine-tremolite-chlorite rock with high metamorphism and later alteration with carbonates (metasomatism) with very coarse gersdorffite associated with tremolite. Probably an altered olivine-enriched cumulate B-zone.

Sample Nº: C-26

Rock Description: Ultramafic (komatiite) with carbonate and tremolite rich rock with massive and disseminated sulphides.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
olivine	9	Relicts of metamorphic olivine altered to serpentine and anthophyllite
Serpentine	16	Alteration on the olivine edges
talc	1	Fine, bright pink prisms in serpentine matrix
tremolite	14	Prismatic aggregates intergroup with gersdorffite
Anthophyllite	10	Big prismatic crystals partially altered
Calcite/dolomite	7	Patchy and sometimes in block (coarse areas), re-crystallised and spotted

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	20	Main sulphide matrix (disseminated) , pale yellow, partially altered.
Pentlandite	8	Cream yellow, rims and flames with pyrrhotite and rare coarse secondary grains
Gersdorffite	10	Formed replacing pyrrhotite and pentlandite with tremolites
Magnetite	5	Skelectal with pentlandite rich zones, very altered

***Tr - trace**

Ore texture/paragenesis:

Bladed and coarse granular olivine with sub-parallel fractures and bright coarse anthophyllite and some chaotic aggregate of tremolite or in fan-like and garbenschiefer bundles with 3 to 5 mm. Massive sulphides with areas of 40 to 50% rich (matrix ore) and disseminated sulphide with coarse secondary gersdorffite.

.**Comments:**

Olivine-tremolite-chlorite schist with high metamorphism and later alteration with carbonates (metasomatism) with very coarse gersdorffite associated with tremolite. Probably an altered olivine-enriched cumulate B-zone.

Sample Nº: C-27

Rock Description: Brecciated massive sulphide with clasts of tremolite-chlorite schist and minor anthophyllite.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	3	Rare in small aggregates
Chlorite	4	Fine, with serpentine matrix
Tremolite	18	Prismatic aggregates in fan like, very common
Anthophyllite	6	Big prismatic crystals partially altered
Dolomite	7	Veins and coarse spots in serpentine matrix

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	38	Main sulphide matrix, pale yellow, partially altered
Pentlandite	14	Cream yellow, very coarse with secondary texture.
Gersdorffite	8	Small inclusions in pyrrhotite and pentlandite formed along aggregates of tremolite+carbonates.
Magnetite	2	Filling cracks in pyrrhotite or pentlandite rich zones
Chalcopyrite	Tr	Traces, small yellow grains rimming pentlandite

***Tr - trace**

Ore texture/paragenesis:

Chaotic aggregate of tremolite-actinolite or in fan-like and garbenschiefer bundles with 5 to 10 mm and decussate chlorite, very fine and small disseminated grains of sulphide. Evidences of replacement of amphiboles by carbonates (dolomite), all sulphides, expect gersdorffite have alteration on edges. Gersdorffite is the coarse or inclusions in massive sulphide (pyrrhotite) and small re-crystallised with carbonate event. No magmatic textures preserved. Chalcopyrite is later in veins or rimming gersdorffite or pentlandite.

Comments:

Tremolite-chlorite schist with high metamorphism and later alteration with carbonates (metasomatism) with very coarse gersdorffite associated with tremolite.

Sample Nº: C-28

Rock Description: Tremolite-Chlorite rock with brecciated sulphides and anthophyllite rich.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	5	Rare in small aggregates
Chlorite	12	Fine, with serpentine matrix
Tremolite	42	Prismatic aggregates in fan like, very common
Anthophyllite	7	Big prismatic crystals partially altered
Dolomite	10	Veins and coarse spots in serpentine matrix

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	12	Main sulphide matrix, pale yellow, partially altered
Pentlandite	6	Cream yellow, very coarse with secondary texture.
Gersdorffite	5	Small inclusions in pyrrhotite and pentlandite formed along aggregates of tremolite+carbonates.
Ferri-Chromite	5	Small, sub-euhedral grains (rare) mostly skeletal
Chalcopyrite	Tr	Inter-grown with pentlandite in aggregate zone

***Tr - trace**

Ore texture/paragenesis:

Chaotic aggregate of tremolite-actinolite, very fine and small disseminated grains of sulphide. Evidences of replacement of amphiboles by carbonates (dolomite), all sulphides, expect gersdorffite have alteration on edges. Gersdorffite is the only re-crystallised with carbonate event. No magmatic textures preserved.

Comments:

Tremolite-chlorite schist with high metamorphism and later alteration with carbonates (metasomatism) with very coarse gersdorffite associated with tremolite. Probably an altered spinifex textured A zone.

Sample Nº: C-29

Rock Description: Tremolite-Chlorite rock with brecciated sulphides and anthophyllite rich.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	1	Rare in small aggregates
Chlorite	2	Along veins and aggregates
Tremolite	22	Prismatic aggregates in fan like, very common
Anthophyllite	11	Big prismatic crystals partially altered
Calcite/dolomite	11	Veins and coarse spots in serpentine matrix

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	29	Main sulphide matrix, pale yellow, massive or net texture
Pentlandite	12	Cream yellow, very coarse with secondary texture (up to 10mm)
Gersdorffite	11	In disseminated, similar to pyrite however whiter and some very coarse grains (porphyroblasts) and also formed along aggregates of carbonates.
Ferri-Chromite	1	Small, sub-euhedral grains (rare) mostly skeletal
Chalcopyrite	Tr	Inter-grown with pentlandite in aggregate zone

***Tr - trace**

Ore texture/paragenesis: Chaotic aggregate of tremolite-actinolite, very fine and small disseminated grains of sulphide. Evidences of replacement of amphiboles by carbonates (dolomite), all sulphides, expect gersdorffite have alteration on edges and coarse grains of anthophyllite. Gersdorffite is the only re-crystallised ore mineral with carbonate zones. No magmatic textures preserved.

Comments:

Tremolite-chlorite schist with high metamorphism and later alteration with carbonates (metasomatism) with very coarse gersdorffite associated with tremolite. Probably an altered spinifex textured A zone.

Sample Nº: C-30

Rock Description: Tremolite-Chlorite rock with brecciated sulphides and anthophyllite rich.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Chlorite	22	Along veins and aggregates
Tremolite	29	Prismatic aggregates in fan like, very common in garbenschiefer bundles
Anthophyllite	28	Big prismatic crystals partially altered
Serpentine	5	Rare in small aggregates

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	10	Main sulphide matrix, pale yellow, massive or net texture
Pentlandite	4	Inclusions in pyrrhotite
Gersdorffite	Tr	Traces and small or cubic
Magnetite/chromite	Tr	Small Skelectal very rare (traces)
Chalcopyrite	Tr	Small inter-grown with pentlandite in aggregate zone

***Tr - trace**

Ore texture/paragenesis:

Disseminated sulphide in amphibole rich zone (tremolite). Sulphides were sieved by amphiboles. Chaotic aggregate of tremolite-actinolite, very fine and small disseminated grains of sulphide. Evidences of replacement of amphiboles by carbonates (dolomite), all sulphides, expect gersdorffite have alteration on edges and coarse grains of anthophyllite. No magmatic textures preserved and gersdorffite is close to magnetite/chromite in brecciated zone.

Comments:

Tremolite-chlorite schist with high metamorphism and later alteration with carbonates (metasomatism) with very coarse gersdorffite associated with tremolite and also indication of some relationship between carbonate alteration and arsenic-bearing minerals? Probably an altered spinifex textured A zone.

Sample Nº: C-31

Rock Description: Massive sulphide with minor clasts of Gangue.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
No classified	30	Reflective sample – no Gangue characterization

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	40	Brown or tint with minor purple oxidized zones areas (anhedral) and anisotropic
Pentlandite	55	Coarse yellow/cream, fractured and partially altered along cracks with round sub-euhedral.
Pyrite	1	Cubic white mineral with high reflectance with no inclusions
Chalcopyrite	2	Coarse very dark yellow, later crystallisation associate with pyrite
Magnetite	2	Generally euhedral crystals, isotropic, and sometimes round in pyrrhotite matrix or in micro veins with pyrrhotite/pentlandite

***Tr - trace**

Ore texture/paragenesis:

Massive sulphide, no primary texture preserved (presence of some exsolution of flames like textures, probably after peak of metamorphism and euhedral magnetite), Remobilization and only secondary alteration due to oxidation and coarse pentlandite.

Comments:

No primary textures and high later re-crystallisation (hydrothermal?) due to very coarse pentlandite in veins with magnetite (oxidation of massive sulphide).

Sample Nº: C-32

Rock Description: Tremolite-Chlorite rock with brecciated sulphides and anthophyllite rich.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Chlorite	9	Along veins and aggregates
Tremolite	7	Prismatic aggregates in fan like, very common in garbenschiefer bundles
Anthophyllite	11	Big prismatic crystals partially altered
Serpentine	30	Main silicate, matrix rich, fine

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	34	Main sulphide matrix, pale yellow, massive or net texture
Pentlandite	8	Inclusions in pyrrhotite
Gersdorffite	Tr	Traces and small or cubic
Magnetite/chromite	Tr	Small Skelectal very rare (traces)
Chalcopyrite	Tr	Small inter-grown with pentlandite in aggregate zone

***Tr - trace**

Ore texture/paragenesis:

Disseminated sulphide in amphibole rich zone (tremolite). Sulphides were sieved by amphiboles. Gersdorffite close to magnetite/chromite in brecciated/alteration zone.

Comments:

Probably an altered olivine-enriched cumulate B-zone but no presence of olivine, and replacement by serpentine? Rock with brecciated sulphides. No evidence of carbonates and poor in arsenic-bearing minerals and later alteration of serpentine. Indication of some relationship between carbonate alteration and arsenic-bearing minerals?

Sample Nº: C-33

Rock Description: Tremolite-Chlorite rock with brecciated sulphides and anthophyllite rich.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Dolomite/Calcite	2	Rimming along veins
Serpentine	37	Main matrix, very fine
Talc	Tr	Small masses very bright along serpentine+calcite alteration edges
Anthophyllite	5	Big prismatic crystals partially altered
Tremolite	10	Prismatic aggregates in fan like

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	37	Main sulphide matrix or in veins, pale yellow, partially altered
Pentlandite	9	Cream yellow, rims and flames with pyrrhotite very small
Magnetite/ferri chromite	tr	Skelectal with pentlandite rich zones, very altered

***Tr - trace**

Ore texture/paragenesis:

Typical disseminated sulphide rock sample with pyrrhotite and pentlandite in serpentine matrix and rare in veins. Small clasts of spinel. Middle section has a tremolite and minor carbonate vein, very re-crystallised (alteration zone).

Comments:

Rock is mainly probably an altered spinifex textured A zone altered by high metamorphism, with potential later weathering features (no presence of olivine, and replacement by serpentine, similar to Barnes et al 2011). Hydrothermal alterations (?) with minor carbonates also no arsenic-bearing minerals present.

Sample Nº: C-34

Rock Description: Ultramafic serpentine rich with disseminated sulphides

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Chlorite	3	Along veins and aggregates
Serpentine	56	Main matrix, very fine
Talc	Tr	Small masses very bright along serpentine+calcite alteration edges
Anthophyllite	tr	Prismatic aggregates in fan like

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	30	Main sulphide matrix or in veins, pale yellow, partially altered
Pentlandite	10	Cream yellow, rims and flames with pyrrhotite very small
Magnetite/ferri chromite	1	In pyrrhotite matrix or mostly micro veins with pyrrhotite/pentlandite

***Tr - trace**

Ore texture/paragenesis:

Disseminated sulphide in ex komatiite, completely serpentinised,

Comments:

Ex olivine-sulphide cumulate komatiite with high serpentinisation (no presence of olivine, and replacement by serpentine, similar to Barnes et al 2011) and no arsenic-bearing mineral present.

Sample Nº: C-35

Rock Description: Bands of massive sulphide chromite rich and ultramafic (cumulate) very altered.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	6	Main matrix with minor magnesite alteration and rare talc, very small grains
talc	tr	Fine, bright pink prisms in serpentine matrix
tremolite	22	Prismatic aggregates intergroup and in fan like
chlorite	6	Along veins and aggregates
dolomite	5	Veins and well crystallised

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	36	Main sulphide matrix, pale yellow, massive or net texture partially altered (purple)
Pentlandite	10	Inclusions in pyrrhotite (small – flames) and sometimes coarser along shear zones
Gersdorffite	5	In chromite rich areas, all sizes and coarser along shear zones with tremolite and carbonates
Magnetite/chromite	10	Elongated, generally in veins or bands with tremolite on the edges
Chalcopyrite	Tr	Small inter-grown with pentlandite in aggregate zone

***Tr - trace**

Ore texture/paragenesis:

Massive sulphide, with no primary texture preserved, strongly foliated and with brecciated zones and portions of massive sulphide chromite rich and bands of tremolite+carbonates in shears with disseminated serpentine (lizardite). Massive sulphide is mostly pyrrhotite with minor pentlandite and big (up to 1mm) crystals of chromite. Gersdorffite is disseminated in chromite rich areas and coarser in shear zones with carbonates.

Comments: massive sulphides veins with high amounts of chromite (very segregated) followed by intense alteration in high stress zone (shears and bands) of tremolite and carbonates (clasts?) with re-orientation and crystallisation of the gersdorffite.

Sample Nº: C-36

Rock Description: massive sulphide veins with chromite-rich and clasts of ultramafic serpentinised (komatiite) with carbonate and tremolite rich rock with.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	7	Main matrix with minor magnesite alteration and rare talc, very small grains
tremolite	10	Prismatic aggregates intergroup and in fan like
chlorite	4	Along veins and aggregates
calcite	4	Veins and well crystallised

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	40	Main sulphide matrix, pale yellow, massive or net texture partially altered (purple)
Pentlandite	18	Inclusions in pyrrhotite (small – flames) and sometimes coarser along shear zones
Gersdorffite	8	In chromite rich areas, all sizes and coarser along shear zones with tremolite and carbonates
Chromite/magnetite	9	Coarse and cubic sometimes I veins and partially altered to magnetite (rimming)
Chalcopyrite	Tr	Small inter-grown with pentlandite in aggregate zone

***Tr - trace**

Ore texture/paragenesis:

Massive sulphide, with no primary texture preserved, strongly foliated and with brecciated zones and portions of massive sulphide chromite rich and bands of tremolite+carbonates in shears with disseminated serpentine (lizardite). Massive sulphide is mostly pyrrhotite with minor pentlandite and big (up to 1mm) crystals of chromite. Gersdorffite is disseminated in chromite rich areas and coarser in shear zones with carbonates.

Comments: massive sulphides veins with high amounts of chromite (very segregated) followed by intense alteration in high stress zone (shears and bands) of tremolite and carbonates (clasts?) with re-orientation and crystallisation of the gersdorffite.

Sample Nº: C-37

Rock Description: Olivine-tremolite-chlorite rock with micro massive veins of sulphides.

Mineralogy: Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Tremolite	33	Prismatic aggregates in fan like, very common and with long crystals and the main mineral
Serpentine	17	Rare in small aggregates
Chlorite	7	Fine, with serpentine matrix
biotite	1	seems to be slightly oblique to the layering, with an imbricate arrangement
Anthophyllite	Tr	Big prismatic crystals partially altered
carbonate	8	Dolomite and rare calcite, mostly in veins and coarse or aggregate in tremolite rich areas

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	17	Small aggregates, disseminated in Gangue, very altered (purple and blue colours)
Pentlandite	8	Small to medium inclusions in pyrrhotite grains, rare flame exsolution preserved.
Gersdorffite	4	Bright, idioblast mineral, coarse formed along aggregates of olivine or tremolite+carbonates
Ferri-Chromite	6	Small, sub-euhedral grains (rare) mostly skeletal and round edges
Chalcopyrite	Tr	Inter-grown with pentlandite in aggregate zone

***Tr - trace**

Ore texture/paragenesis: Chaotic aggregate of tremolite-actinolite or in fan-like and garbenschiefer bundles with 7 to 12mm and decussate chlorite, very fine and small disseminated grains of sulphide. Evidences of replacement of amphiboles by carbonates (dolomite), all sulphides, expect gersdorffite have alteration on edges. Gersdorffite is the coarse or inclusions in massive sulphide (pyrrhotite) and small re-crystallised with carbonate event. No magmatic textures preserved. Chalcopyrite is later in veins or rimming gersdorffite or pentlandite.

Comments: Olivine-tremolite-chlorite schist with high metamorphism features not well preserved (no evident metamorphic olivine) and later alteration with carbonates (metasomatism) with very coarse gersdorffite associated with tremolite. Probably an altered olivine-enriched cumulate B-zone.

Sample Nº: C-38

Rock Description: Massive sulphide chromite rich with inclusions of gangue m

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
No classified	4	Reflective sample – no Gangue characterization

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	55	Brown or tint highly altered with purple colour in oxidized zones areas. Minor parts brecciated.
Pentlandite	27	Coarse yellow/cream, fractured and partially altered along cracks with round sub-euhedral.
Gersdorffite	8	In chromite rich areas, all sizes and coarser along shear zones with tremolite and carbonates
Chalcopyrite	Tr	Inter-grown with pentlandite in aggregate zone
Magnetite/chromite	6	Light grey with zonation and crystals with hexagonal shape

***Tr - trace**

Ore texture/paragenesis:

Massive sulphide, with no primary texture preserved, strongly foliated and with brecciated zones with gersdorffite present. Magnetite is present and it is mostly with zonation and crystals with hexagonal shape. Potential remobilization and only secondary alteration due to oxidation.

Comments:

Strongly foliated, pyrrhotite rich and partially altered, rich zones of magnetite and gersdorffite and possible hydrothermal (crystallisation of gersdorffite and cobaltite) and oxidation (magnetite) alterations .

Sample Nº: C-39

Rock Description: Ultramafic with disseminated sulphides with minor carbonate alteration and micro massive sulphide veins.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Olivine	40	Neoblastic metamorphic bladed olivine altered to serpentine and anthophyllite
Serpentine	25	Alteration matrix with remaining of olivine
Dolomite	6	Massive veins and spots in serpentine alteration zones
Talc	Tr	Small masses very bright along serpentine+calcite alteration edges
Chlorite	2	Coarse re-crystallised zones (clinochlore)

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	17	Disseminated minor sporadic massive areas
Pentlandite	4	Small, flames structures in pyrrhotite areas
Pyrite	5	Small sub euhedral grains
Magnetite	1	In joints and filling cracks

***Tr - trace**

Ore texture/paragenesis:

Mesh texture, granular meta olivine and fine grained with some lizardite alteration. Typical disseminated sulphide rock sample with pyrrhotite and pentlandite in serpentine matrix and rare in veins. Dolomite alterations very coarse and patchy.

Comments:

Ex olivine-sulphide cumulate komatiite affected by high metamorphism (presence of metamorphic olivine) replaced by later serpentinisation. Some alteration of carbonates present.

Sample Nº: C-40

Rock Description: Serpentinised ultramafic rock with disseminated sulphides with carbonate alteration.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Olivine	5	Relicts of metamorphic bladed olivine altered to serpentine
Serpentine	55	Main mineral, replacing olivine (lizardite)
Magnesite	5	Well crystallised in serpentine matrix
tremolite	1	Small and rare and in fan like
Chlorite	2	Coarse re-crystallised zones (clinochlore)

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	20	Disseminated and with bladed shapes
Pentlandite	7	Coarse yellow/cream, fractured and partially altered along cracks with round sub-euhedral.
Pyrite	2	Rare cubic, generally inside pyrrhotite matrix
Magnetite	3	In joints and filling cracks or rimming pyrrhotite

***Tr - trace**

Ore texture/paragenesis:

Disseminated sulphide in ex komatiite completely serpentinised. Magnesite alterations and presence of minor pyrite and magnetite (oxidation phases)

Comments:

Serpentinised olivine-sulphide cumulate komatiite with high serpentinisation (no presence of olivine, and replacement by serpentine, similar to Barnes et al 2011) and no arsenic-bearing mineral present.

Sample Nº: C-41

Rock Description: Brecciated olivine-tremolite-chlorite rock with micro massive veins of sulphides.

Mineralogy: Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
olivine	13	Relicts of metamorphic olivine altered to serpentine and anthophyllite and sometimes with magnetite rimming
Serpentine	31	Main matrix with minor magnesite alteration and rare talc
Chlorite	10	Coarse re-crystallised zones along anthophyllite (clinochlore)
tremolite	4	Prismatic aggregates intergroup with gersdorffite
Anthophyllite	4	Big prismatic crystals partially altered by chlorite
Calcite	4	Veins and spots in serp. matrix

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	19	Main sulphide matrix, pale yellow.
Pentlandite	7	Coarse, cream yellow, rims with pyrrhotite and very coarse secondary grains
Gersdorffite	5	Bright, idioblast mineral, coarse formed along aggregates of olivine or tremolite+carbonates
Chromite	1	Coarse and cubic sometimes I veins and partially altered to magnetite (rimming)
Pyrite	Tr	Inclusions in pentlandite and pyrrhotite matrix, coarse
Magnetite	2	Mostly on the alteration of olivine

***Tr - trace**

Ore texture/paragenesis:

Bladed and coarse granular olivine with sub-parallel fractures and bright coarse anthophyllite and tremolite with chlorite filling the gaps between other silicates. Massive sulphides in brecciated zones and disseminated sulphide with coarse secondary gersdorffite.

Comments: Serpentinised olivine-tremolite-chlorite rock (probably an altered olivine-enriched cumulate B-zone). Some alteration assemblages rich in carbonates and tremolite-actinolite with very coarse gersdorffite replacing pyrrhotite and pentlandite

Sample Nº: C-42

Rock Description: Altered matrix and disseminated sulphide olivine-cumulate rock with carbonate rich zones.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	11	Main matrix with minor magnesite alteration and rare talc, very small grains
Olivine	57	Coarse and core preserved
chlorite	Tr	Along veins and aggregates
dolomite	8	Spotted and well crystallised in massive areas

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	9	Main sulphide matrix, pale yellow, massive or net texture partially altered (purple)
Pentlandite	3	Inclusions in pyrrhotite (small – flames) and sometimes coarser along shear zones
Magnetite	1	Coarse and cubic sometimes I veins and partially altered to magnetite (rimming)
Pyrite	11	Inclusions in pentlandite and pyrrhotite matrix, coarse

***Tr - trace**

Ore texture/paragenesis:

No stress or shear presents in the thin section, carbonate only spotted. Disseminated sulphide (mesh texture), magnetite mostly anastomosing and minor chlorite. Also presence of minor pyrite and magnetite (oxidation phases).

Comments:

Ex olivine-sulphide cumulate komatiite affected by high metamorphism (presence of metamorphic olivine) and partially replaced by later serpentinisation. Some alteration of carbonates present.

Sample Nº: C-43

Rock Description: Massive sulphides and clasts of ultramafic with disseminated sulphide.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	7	Fine and very sparse
Talc	Tr	Fine, bright pink prisms in serpentine matrix
Calcite	5	Veins along sulphides or inclusions in massive areas with rhombohedral crystals

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	54	Massive and sometimes altered
Pentlandite	25	Cream yellow coarse and blocky
Magnetite	5	Rare, elongated common in brecciated zone, filling cracks in massive sulphide areas
Pyrite	3	Inclusions in pentlandite and pyrrhotite matrix, coarse

***Tr - trace**

Ore texture/paragenesis:

Porphyroblasts of pyrite in massive sulphide zones. Re-crystallisation on secondary pentlandite in veins or massive zones, rare magnetite in cracks (fillings) and ferri-chromite sub euhedral and partially replaced by magnetite. The presence of minor pyrite and magnetite may represent an oxidation phase.

Comments:

No primary textures and high later re-crystallisation (hydrothermal?) due to very coarse pentlandite in veins with magnetite (oxidation of massive sulphide). Some alteration assemblage rich in carbonate (metasomatism?).

Sample Nº: C-44

Rock Description: Massive sulphides and clasts of ultramafic with disseminated sulphide. komatiite.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
olivine	2	Relicts of metamorphic olivine altered to serpentine and anthophyllite
Serpentine	7	Fine and very sparse
talc	Tr	Fine, bright pink prisms in serpentine matrix
Anthophyllite	2	Big prismatic crystals (one with 30mm) mostly altered to talc
Calcite	5	Veins along sulphides or inclusions in massive areas

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	54	Massive and sometimes sieved by amphiboles
Pentlandite	25	Cream yellow coarse and blocky
Chromite	5	Rare, sub euhedral enclosed in serpentine rich areas
Millerite	Tr	Traces, small yellow grains with pyrrhotite

***Tr - trace**

Ore texture/paragenesis:

Porphyroblasts of pyrite in massive sulphide zones. Re-crystallisation on secondary pentlandite in veins or massive zones, rare magnetite in cracks (fillings) and ferri-chromite sub euhedral and partially replaced by magnetite. The presence of minor pyrite and magnetite may represent an oxidation phase.

Comments:

Brecciated massive sulphide ore type with later metamorphic olivine may indicate areas affected by peak of metamorphism. Later serpentinisation overprints the pre-alteration silicates (weathering process?).

Sample Nº: C-45

Rock Description: Ultramafic with disseminated sulphide with intense carbonate alteration and sulphide re-crystallisation along shears (visible gersdorffite).

Mineralogy: Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	31	Matrix with mesh texture
dolomite	8	Veinlets or along alteration edges and spots in serp. matrix
Tremolite-actinolite	Tr	Rare inside carbonate grain
phlogopite	6	Aggregates in carbonates, later crystallisation and along massive contact zone
Anthophyllite	2	Big parts of the original prismatic crystals
olivine	Tr	Relicts of metamorphic olivine altered to serpentine and anthophyllite

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	30	Main sulphide matrix, pale yellow. disseminated or in small veins
Pentlandite	13	Inclusions in pyrrhotite (small – flames) and sometimes coarser along shear zones
Chalcopyrite	5	Inter-grown with pentlandite in aggregate zone or filling cracks in massive sulphide areas in new young fractures.
Gersdorffite	Tr	Rare, very fine and round, only 5 grains found
Magnetite	3	Coarse and cubic sometimes in veins and partially altered to magnetite (rimming)
Millerite	2	Traces, small yellow grains with pyrrhotite or filling cracks in massive sulphide areas in new young fractures.

***Tr - trace**

Ore texture/paragenesis: Ultramafic with disseminated sulphide in net texture with pyrrhotite + pentlandite. Coarse anthophyllite crystals and intense alteration of carbonates (Metasomatism) resulting in the alteration of neoblasts of olivine. Intense arsenic alteration and re-crystallisation of gersdorffite with shear zone of 2.5cm with veins of gersdorffite and edges of calcite (inclusions of pyrrhotite + pentlandite, spinel, lizardite and anthophyllite.

Comments: Ex olivine-sulphide cumulate with disseminated texture (matrix ore type) altered by high metamorphism (presence of secondary olivine from previous anthophyllite). Presence of later alteration with carbonates.

Sample Nº: C-46

Rock Description: Ultramafic partially serpentinised (komatiite) with carbonate and minor tremolite rich rock with disseminated sulphides

Mineralogy: Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	22	Main matrix with minor magnesite alteration and rare talc, very small grains
Olivine	40	Coarse and core preserved
chlorite	6	Along veins and aggregates
dolomite	11	Spotted and well crystallised in massive areas
tremolite	3	Small and rare and in fan like

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	10	Main sulphide matrix, pale yellow, massive or net texture partially altered (purple)
Pentlandite	3	Inclusions in pyrrhotite (small – flames) and sometimes coarser along shear zones
Magnetite	2	Coarse and cubic sometimes in veins and partially altered to magnetite (rimming)
Pyrite	3	Inclusions in pentlandite and pyrrhotite matrix, coarse

***Tr - trace**

Ore texture/paragenesis: No stress or shear presents in the thin section, carbonate only spotted. Disseminated sulphide (mesh texture), magnetite mostly anastomosing and minor chlorite.

Comments: Ex olivine-sulphide cumulate komatiite with serpentinisation (olivine replaced by serpentine, similar to Barnes et al 2011). Some alteration assemblages rich in carbonates and tremolite with coarse pyrite replacing pyrrhotite.

Sample Nº: C-47

Rock Description: Tremolite-Chlorite rock with brecciated sulphides anthophyllite rich and intense carbonate alteration

Mineralogy: Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
serpentine	11	Small areas preserved, hard to identify
tremolite	10	Prismatic fine 0.1 to 0.3mm in diameter, some aggregates intergroup with gersdorffite
Anthophyllite	5	Small parts preserved, mostly replaced by tremolites and
Carbonates(magnesite+dolomite)	25	Massive areas, main Gangue mineral and with some coarse aggregates

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	20	Mostly round and altered by carbonates
Pentlandite	11	Small inclusions and exsolution in pyrrhotite grains
Gersdorffite	5	Bright, idioblast mineral, fine to coarse formed included in chromite and pyrrhotite
Chromite (ferri-chromite)	3	Coarse and cubic sometimes I veins and partially altered to magnetite (rimming) and rare skeletal
Magnetite	10	Coarse grains, generally alterations on chromites, sometimes elongated in shears and oriented.

***Tr - trace**

Ore texture:

Main texture is brecciated and intense presence of shears zones, extremely altered, no primary textures preserved with chaotic fine tremolite 0.1 to 0.3mm in diameter, some aggregates intergroup with gersdorffite and massive zones of carbonates.

Comments:

Altered tremolite-chlorite schist with brecciated micro veins of sulphides (from the main matrix ore zone) and spinel (chromite). Extremely affected by metasomatism event and carbonate overprints majority of the gangue minerals. Presence of small round pyrrhotite and common coarse veins of magnetite and gersdorffite. Probably an altered spinifex textured A zone.

Sample Nº: C-48

Rock Description: Massive sulphides and small clasts of carbonates

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Carbonates	3	Small clasts inside massive sulphide

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	61	Massive and sometimes sieved by amphiboles , some purple and anisotropic, main sulphide
Pentlandite	29	Cream yellow coarse and blocky mostly along cracks
Gersdorffite	5	Bright, idioblast mineral, fine , isotropic and round
Millerite	Tr	Yellow rims around pentlandite
Magnetite	2	Distinct grey minerals filling cracks and sometimes cubic, euhedral, generally on edges of pyrrhotite.

***Tr - trace**

Ore texture/paragenesis:

Massive pyrrhotite matrix, partially altered. Re-crystallisation evident by secondary pentlandite in veins or massive zones, magnetite in cracks (fillings) and round altered gersdorffite.

Comments:

Massive sulphide, along shear zones and re-crystallised (coarse pentlandite) by later metamorphic events.

Sample Nº: C-49

Rock Description: Massive sulphide and altered ultramafic with intense carbonatization

Mineralogy: Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
serpentine	tr	Small rare areas preserved, patchy
tremolite	tr	Mostly altered to carbonates, with core of crystals mostly preserved
Anthophyllite	tr	Small parts preserved, mostly replaced by tremolites and
Calcite and dolomite	35	Massive areas, main Gangue mineral and with some coarse and fibrous aggregates

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	35	Massive and sometimes sieved by amphiboles , some purple and anisotropic, main sulphide
Pentlandite	17	Small inclusions and exsolution in pyrrhotite grains, also some recrystallised and coarse (block) in shears
Gersdorffite	10	Very common white mineral, hard, some round shapes and inclusions in chromite, mostly in carbonate or pyrrhotite matrix, in micro veins or disseminated.
Chromite (ferri-chromite)	3	Mostly with round edges and skeletal texture, presence of small rare inclusions of gersdorffite
Violarite	tr	Small very intense purple mineral in intensively altered area.

Ore texture: Sample is composed mainly by carbonates and secondary massive and disseminated sulphides and sulpharsenides. Main sulphide is pyrrhotite (matrix) and scatted to some extent coarse pentlandite. Gersdorffite is common and shows different varieties in veins or rimming carbonates and chromite, rare cases of small inclusions in the last.

Comments: Altered olivine-sulphide cumulate komatiite with disseminated sulphides (matrix ore type) and spinel, chromite. Extremely affected by metasomatism event and carbonate overprints majority of the gangue minerals, rare amphiboles preserved and various types of gersdorffite formation.

Sample Nº: C-50

Rock Description: Altered ultramafic tremolite rich with disseminated sulphides and carbonate alteration

Mineralogy: Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Olivine	6	Relicts of metamorphic bladed olivine altered to serpentine
serpentine	10	Small rare areas preserved, patchy
tremolite	29	Mostly altered to carbonates, core and pale crystals shapes preserved
Anthophyllite	3	Altered crystals, mostly altered to serp
Calcite and dolomite	14	Mostly recrystallised in shears and rare spotted

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	20	Massive and sometimes sieved by amphiboles , some purple and anisotropic, main sulphide
Pentlandite	10	Small inclusions and exsolution in pyrrhotite grains, also some recrystallised and coarse (block) in shears
Gersdorffite	5	Very common white mineral, hard, some round shapes and inclusions in chromite, mostly in carbonate or pyrrhotite matrix, in micro veins or disseminated.
Chromite (ferri-chromite)	3	Mostly with round edges and skeletal texture, presence of small rare inclusions of gersdorffite
Millerite	Tr	Yellow rims around pentlandite

Ore texture: Tremolite is the main gangue and main sulphide is pyrrhotite (matrix) with scattered coarse pentlandite. Gersdorffite is common and shows different varieties in veins or rimming carbonates and chromite, rare cases of small inclusions in the last.

Comments: Altered olivine-tremolite-schist with strings of sulphides (micro massive veins) and spinel, chromite. Extremely affected by metasomatism event and carbonate overprints majority of the gangue minerals, various types of gersdorffite formation. Probably an altered spinifex textured A zone.

Sample Nº: C-51

Rock Description: Serpentinite disseminated sulphides ultramafic rock with carbonate alteration.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Olivine	tr	Relicts of metamorphic bladed olivine altered to serpentine
Serpentine	51	Main mineral, replacing olivine (lizardite) in mesh texture
Dolomite	17	Veins and spots in serp. matrix
Brucite	4	Small clayish looking minerals, very altered

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	19	Disseminated and with bladed shapes
Pentlandite	6	Coarse yellow/cream, fractured and partially altered along cracks with round sub-euhedral.
Gersdorffite	2	White mineral, hard, some round shapes and inclusions in chromite, mostly in carbonate or pyrrhotite matrix, in micro veins or disseminated.
Chromite (ferri-chromite)	1	Mostly with round edges and skeletal texture, presence of small rare inclusions of gersdorffite

***Tr - trace**

Ore texture/paragenesis:

Disseminated sulphide (mesh texture), with serpentine replacing bladed metamorphic olivine. Rock sample with pyrrhotite and pentlandite in serpentine matrix and rare in veins. gersdorffite mostly fine associated with carbonate rich areas

Comments:

Serpentinised olivine-sulphide cumulate komatiite with high serpentinisation (no presence of olivine, and replacement by serpentine, similar to Barnes et al 2011).Some alteration assemblages rich in carbonates (metasomatism) also associated with gersdorffite.

Sample Nº: C-52

Rock Description: Massive carbonate and massive sulphide rock with clasts of serpentine rich ultramafic.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Calcite	12	Rhombohedral and fine matrix with disseminated sulphides and serpentine
Dolomite	16	Similar to calcite with higher birefringence
Serpentine	Tr	Aggregates with calcite
chlorite	Tr	Rare alterations along edges of serpentine

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	40	Main matrix, some net texture replaced by gersdorffite
Pentlandite	12	Cream yellow fractures in pyrrhotite rich zones
Gersdorffite	9	White mineral, hard, with all sized some round shapes and inclusions in chromite, mostly in carbonate or pyrrhotite matrix, in micro veins or disseminated.
Ferri-chromite /magnetite	10	Coarse and minor round, mostly in brecciated areas
Cobaltite	1	Alteration in early gersdorffite types, higher in Co, mostly as exsolution and inclusions in pyrrhotite

***Tr - trace**

Ore texture/paragenesis:

Chaotic aggregate of calcite and serpentine, very fine and small disseminated grains of sulphide + ferri-chromite. Evidences of replacement of serpentine by carbonates (calcites), all sulphides, gersdorffite have alteration on edges. Gersdorffite is the only sulphur rich mineral re-crystallised with carbonate events.

Comments:

Metasomatism event alteration on previous remobilized massive sulphide veins.

Sample Nº: C-53

Rock Description: Retrogressed laminated fine-grained metasiltstone or metasandstone:

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
quartz	40	grains from 0.05mm to 0.1mm in diameter
plagioclase	30	and totally sericitised fine-grained, commonly with poor textural preservation
chlorite	10	Relatively minor partly clay altered (brucite?)
biotite	10	basal sections suggesting a schistosity at a high angle to the core axis and oblique to the layering
muscovite	7	adjacent to the lenses (quart rich), mostly parallel to the layering and probably representing boudinaged veins
adularia	Tr	In late veins to 0.3mm wide occur, at a high angle to the layering
tourmaline	3	There are also layer-parallel lenses rich in inequigranular quartz

*Tr - trace

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrite	Tr	Rare and very fine adjacent to a layer-parallel quartz-rich lens

*Tr - trace

Rock texture:

Thin section was taken is composed of finely laminated grey metasediment with probable bedding laminations at about 35-40°. Former quartz-feldspar-biotite schist with minor muscovite and tourmaline: the feldspar has been totally sericitised with clays or chlorite replacing biotite. Layer-parallel quartz boudins contain muscovite or chloritised biotite, with layer-parallel stylolites and crosscutting adularia-prehnite veins containing carbonate and clinozoisite.

Comments:

Pyrite is the only sulphide found in this section

Sample Nº: C-54

Rock Description: Contact between a green hornblende-rich lithology and a plagioclase-rich amphibolite

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
hornblende	70	Main mineral, non-oriented green colour, partly decussate but with suggestions of recrystallised micro spherulitic aggregates and lenses of relatively oriented amphibole
plagioclase	tr	altered to sericite
clinozoisite	tr	Scatted in the section
chlorite	4	Scatted in the section or oriented in veins
carbonate	9	large lens or vein rich in carbonate
quartz	17	Diverse types, mostly in veins or masses
titanite	tr	small and patches of interstitial quartz

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrite	Tr	Rare and very fine adjacent to a layer-parallel quartz-rich lens

***Tr - trace**

Rock texture:

The edge of the amphibole-rich zone is marked by a quartz vein 1-3mm with into which minor hornblende has protruded. The adjacent zone is rich in sericitised feldspar with minor clinozoisite. There is also a large lens or vein rich in carbonate, lenses and masses of hornblende and lenses of probable vein-quartz. Titanite is disseminated through the hornblende and former plagioclase-rich areas.

Comments:

Pyrite is the only sulphide found in this section

Sample Nº: C-55

Rock Description: Quartz-epidote-clinozoisite-muscovite schist

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
quartz	55	micromosaic to 0.4mm in grainsize and quartz-poor to quartz-free areas
epidote	15	possible zoisite or clinozoisite, muscovite and possible prehnite.
muscovite	20	flakes and poikiloblastic crystals
titanite	tr	disseminated
plagioclase	10	partially altered to sericite

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrite	Tr	Rare and very fine

***Tr - trace**

Rock texture:

The epidote is fine-grained and granular to prismatic, with mostly fibrous zoisite or clinozoisite showing lower birefringence compared to that of epidote. The zoisite-like mineral could be hydrated calcium silicate, but an epidote-group mineral is more probable. There is trace pyrite.

Comments:

This sample may represent quartz/feldspathic metasediment with calc-silicate alteration and retrograde metamorphism. The textures are complex but there may be a quartz-rich vein across the thin section.

Sample Nº: C-56

Rock Description: Quartz-microcline-plagioclase-garnet-biotite schist

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
quartz	42	abundant micromosaic or in boudins, from 1mm to 7mm long, partly rimmed by or intergrown with garnet and rarely enclosing sulphide
microcline	30	abundant micromosaic
plagioclase	4	less abundant partly clouded
biotite	10	disseminated fine-grained in micromosaic
muscovite		sparse and rare
chlorite	4	locally passing into elongate inclusion-rich garnet grains from 0.5mm to 8mm long. More rounded, inclusion-poor garnet also occurs, to 3mm long, but is much less abundant than the elongate garnet
garnet	7	partly in and adjacent to quartz-rich boudins

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
pyrrhotite	3	lenses about 1mm long
chalcopyrite	tr	rare and fine in pyrrhotite rich areas
pyrite	tr	rare and fine in pyrrhotite rich areas

***Tr - trace**

Rock texture:

The core-segment consists of dark grey schist with probable garnets partly elongate parallel to the foliation

Comments:

This is high-grade semipelitic schist with garnet + K-spar derived from biotite + muscovite. Muscovite, chlorite, epidote and sericite are all retrograde.

Sample Nº: C-57

Rock Description: Quartz-plagioclase-biotite-hornblende schist

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
quartz	45	abundant micromosaic to 0.2mm
microcline	30	abundant micromosaic
plagioclase	9	less abundant partly clouded
hornblende	5	partly foliated but less schistose than the biotite
biotite	10	seems to be slightly oblique to the layering, with an imbricate arrangement
apatite	1	minor disseminated

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
pyrrhotite	1	lenses about 1mm long
pyrite	tr	rare and fine in pyrrhotite rich areas

***Tr - trace**

Rock texture:

The sample shows lamellae of schistose biotite to 0.4mm in grainsize separated by an abundant quartz+feldspathic micromosaic to 0.2mm in grainsize with probable plagioclase clearly visible only adjacent to hairline fractures with possible clays, where any feldspar has been clouded.

Comments:

This sample represents metamorphosed semipelitic sediment.

Sample Nº: C-58

Rock Description: Heterogeneous quartz-feldspar-biotite schist

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
sericite-clouded plagioclase	13	mostly elongate lenses to 6mm long composed variously of
quartz	40	abundant micromosaic and also elliptical lenses of polycrystalline quartz to 3mm long that could represent quartz phenocrysts.
microcline	34	abundant micromosaic
muscovite	5	with grains mostly less than 0.4mm in diameter
biotite	7	disseminated and in lenses to 4mm long, possibly representing mafic phenocrysts.

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
pyrrhotite	1	rare and fine, disseminated
pyrite	tr	rare and fine in pyrrhotite rich areas

***Tr - trace**

Rock texture:

Sample is partly lenticular, mostly parallel veins to 1.5mm wide are mostly quartz-rich with minor biotite but some segments contain microcline and/or plagioclase. It seems possible that this sample represents metamorphosed quartz-feldspar-porphyritic volcanic or subvolcanic material with recrystallised phenocrysts and a quartz-feldspar-biotite matrix or groundmass and parallel veins.

Comments:

Possibly derived from porphyritic acid volcanic material, with sparse sulphide and parallel quartz-rich veins.

Sample Nº: C-59

Rock Description: Quartz-feldspar-biotite schist with garnet

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
quartz	45	mostly laminated with abundant to 0.25mm in grainsize and lamellae with clouded albite, sericite and epidote
albite	15	mostly elongate or in micromosaic
sericite	10	mostly elongate or in micromosaic
epidote	5	mostly elongate or in micromosaic
biotite	15	seems to be slightly oblique to the layering, with an imbricate arrangement
apatite	2	minor disseminated
garnet	8	rains to 8mm long, generally with very minor clay-altered biotite

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
pyrrhotite	tr	Patchy
pyrite	tr	Rare and patchy

***Tr - trace**

Rock texture:

This sample is finely laminated schist with white veins oblique to the foliation and represents retrogressed garnet-bearing possible quartz-feldspar-biotite schist with garnet in lenses with quartz, sericite-epidote-clay-chlorite alteration and prehnite-quartz veins ± chlorite ± sulphide.

Comments:

Retrogressed, garnet-bearing apparent quartz-feldspar-biotite schist. Garnet in lenses with quartz, sericite-epidote-clay-chlorite alteration and prehnite-quartz veins ± chlorite ± trace sulphide.

Sample Nº: C-60

Rock Description: Metamorphic dunite with minor disseminated sulphides and oxides

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
olivine	90	Most of the rock is relatively massive fine-grained metamorphic olivine from 0.2mm to 2mm in grainsize, but with areas containing olivine to 6mm long (metamorphic)
chlorite	3	disseminated as flakes to 1mm in and between olivine grains

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
pyrrhotite	4	Disseminated and with bladed shapes
pentlandite	1	Fine, exsolution in pyrrhotite
millerite	2	unidentified lamellae
chromite/magnetite	tr	Mostly with round edges and skeletal texture and filling cracks

***Tr - trace**

Rock texture:

Ex-dunite, olivine-rich aggregate relatively massive fine-grained metamorphic olivine from 0.2mm to 2mm in grainsize, but with areas containing olivine to 6mm long (metamorphic)with chlorite and sulphides, rare chromite. The sulphide is in aggregates to 1mm in diameter, locally composite with magnetite

Comments:

This sample represents a dunite with minor secondary chlorite.

Sample Nº: C-61

Rock Description: Metamorphic dunite with rare disseminated sulphides and oxides

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
olivine	90	Main mineral, inequigranular metamorphic olivine from 0.2mm to 2mm in grainsize.
serpentine	5	in a network of hairline fractures
chlorite	3	occurs between olivine grains

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
magnetite	1	disseminated and very minor fine-grained
pyrrhotite	1	disseminated and with bladed shapes
pentlandite	tr	fine, exsolution in pyrrhotite

***Tr - trace**

Rock texture:

Inequigranular, mostly fine-grained metamorphic olivine rock with sparse serpentine, chlorite, magnetite and sulphide

Comments:

This sample represents a dunite with minor secondary chlorite and later serpentine partial alteration

Sample Nº: H-01

Rock Description: serpentinised olivine-cumulate with disseminated sulphides

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Serpentine	65	-(lizardite) main mineral with bladed structures remaining (neoblastic olivine)
Tremolite	tr	Rare, mostly small along shears
Chlorite	10	Small tabular close to coarse rich zones of lizardite
Talc	1	Rare masses of very bright minerals along serpentine+calcite alteration edges
Olivine	5	Some small core preserved with serpentine on the rims

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	10	Main sulphide matrix, pale yellow or brown
Pentlandite	4	Cream yellow, rims and flames with pyrrhotite and rare coarse secondary grains
Magnetite	4	Inter-grown and lamellae with pyrrhotite and pentlandite, sometimes rimming old olivine in serp matrix
Pyrite	1	In high straighten zones, generally with talc

***Tr - trace**

Ore texture/paragenesis:

Disseminated sulphide rock serpentine rich, derived from granular metamorphic olivine-cumulate ultramafic with disseminated sulphide iron rich, presence of mesh texture. Magnetite rimming altered olivine + serp.

Comments:

Serpentinised olivine-sulphide cumulate altered by high metamorphism with metamorphic olivine and later alteration of serpentine. No primary textures or structures preserved.

Sample Nº: H-02

Rock Description: serpentinised olivine-cumulate with disseminated sulphides and coarse non oriented anthophyllite.

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
olivine	10	Relicts of metamorphic olivine altered to serpentine and anthophyllite and with jack straw texture
Serpentine	36	Main matrix with mesh texture and alteration
talc	3	Fine, bright pink prisms in serpentine matrix
Anthophyllite	15	Big prismatic crystals partially altered
magnesite	7	Veins and spots in serp. Matrix. Fluid inclusion in some coarse examples

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	15	Main sulphide matrix, pale yellow, partially altered
Pentlandite	5	Cream yellow, rims with pyrrhotite and rare coarse secondary grains
Magnetite	4	Inter-grown and lamellae with pyrrhotite and pentlandite, sometimes rimming old olivine in serp matrix, mostly filling cracks
Gersdorffite	5	Bright, idioblast mineral, coarse formed along aggregates of olivine or tremolite+carbonates

***Tr - trace**

Ore texture/paragenesis: Bladed and coarse granular olivine with sub-parallel fractures and bright coarse Anthophyllite. Massive sulphides in brecciated zones and disseminated sulphide with coarse secondary gersdorffite.

Comments: Serpentinised olivine-sulphide-cumulate altered by high metamorphism with metamorphic olivine and later alteration of serpentine (lizardite) and chlorite rich. Some evidence of carbonate alteration associated with minor amounts of gersdorffite replacing pyrrhotite and pentlandite.

Sample Nº: H-03

Rock Description: Contact meta-gabbro and ultramafic with disseminated sulphides

Mineralogy:

Gangue Minerals:

Mineral	Mode (%)	Textural features of mineral
Tremolite	5	Small fan like aggregates
Cummingtonite	25	Very fine matrix with talc riming some crystals
Biotite	10	Two types, on ultramafic – fine and disseminated, and elongated and oriented on meta mafic
Clinopyroxene	2	Small rare grains, very altered
talc	Tr	
quartz	5	Granular, small in micromosaic
plagioclase	20	Granular, small in micromosaic
hornblende	10	
calcite	2	Small alterations along amphiboles grains
Augite	1	Small crystals, clear cleavage
tourmaline	Tr	Oriented with biotite
Chlorite	5	Alterations of pyroxenes

***Tr - trace**

Ore Minerals:

Mineral	Mode (%)	Textural features of mineral
Pyrrhotite	10	Associated with pentlandite, mostly as fainted in disseminated net texture and main mineral in small massive sulphide vein.
Pentlandite	4	Cream yellow, strong cleavage and triangular shapes.
Gersdorffite	1	Small white grains in massive sulphide zone along contact and filling young fractures
Chalcopyrite	Tr	Later, alteration of Pyrrhotite and in foliation along shears
magnetite	tr	Filling small cracks and disseminated in meta gabbro

***Tr - trace**

Ore texture:

Two rock types – ultramafic is very altered with amphiboles and talc as main matrix (very fine) with minor amounts of biotite and rare pyroxenes preserved and one massive vein along contact zone.

Meta gabbro has brecciated textures on the contact zone and micromosaic (plagioclase and minor quartz) on the other side of the section. Hornblende, chlorite and biotite are partially oriented and small rare pyroxene preserved in hornblende rich zones.

Comments:

Contact zone, very brecciated and chaotic (hornblende +mafic platy minerals) and magnetite+ pyrrhotite +pentlandite also with brecciated texture. Later small metasomatism, which is evident by alterations of carbonates and coarse non oriented amphiboles and sulphides.

APPENDIX 4. Mineral composition undertaken by quantitative SEM with EDS and Images

Twenty-two samples were examined and analysed using quantitative methods to calculate the ratio of the elemental composition of sulphide, sulpharsenide and oxides at Curtin Electron Microscope Laboratories, Department of Imaging & Applied Physics. The composition of the arsenic-bearing minerals and adjacent minerals was determined by energy-dispersive X-ray spectroscopy microanalysis, using a Zeiss Evo 40XVP scanning electron microscope with an attached Oxford Instruments energy dispersive X-ray detector (EDS). Primary metal and mineral standards were used for calibration. Sulphides and Oxides were analysed using the following X-ray lines Fe *Kα*, Co *Kα*, Ni *Kα*, Cu *Kα*, Cr *Kα,* Sb *Kα*, Ga *Kα*, As *Kα* and S *Kα.* The metals standards utilised include: Fe, Co, Ni, Cu and Cr*;* and mineral standards were used for Sb, Ga, As (GaAs and SbAs) and S (FeS). The operating conditions were in controlled pressure mode with a chamber pressure of between 0.1 to 0.5 Mbar, accelerating voltage of 20kv, beam current of 45 nA, working distance of 8.5mm, with a counting time of 100 seconds per spectrum and detection limit of 1% (EDS detection limit of 0.01% and precision of 1.0%). The following table includes the list of points and samples analysed from sulphide, sulpharsenide and oxides minerals. A value with “b.d.l.” represents analyses below detection limits and all values reported are on weight percentage (wt %)

Table A4.1 SEM EDS Analytical report - pyrrhotite mineral raw data

Point_ID	Sample	S K	Fe K	Pt M	Ni K	Cr K	Total
1	c-24	41.79	61.32	b.d.l	b.d.l	b.d.l	103.11
2	c-24	40.69	60.35	b.d.l	b.d.l	b.d.l	107.34
3	c-24	40.88	59.32	b.d.l	b.d.l	b.d.l	100.2
4	c-24	39.67	61.69	b.d.l	b.d.l	b.d.l	108.07
5	c-24	41.84	61.15	b.d.l	b.d.l	b.d.l	110.19
6	c-35	39.82	58.22	b.d.l	b.d.l	b.d.l	98.04
7	c-35	39.52	57.64	b.d.l	b.d.l	b.d.l	97.16
8	c-36	37.76	59.32	b.d.l	b.d.l	b.d.l	97.08
9	c-36	38.22	58.06	b.d.l	b.d.l	b.d.l	96.28
10	c-36	38.34	60.45	b.d.l	b.d.l	b.d.l	110.64
11	c-36	39.6	59.77	b.d.l	b.d.l	b.d.l	99.37
12	c-47	41.68	60.27	b.d.l	b.d.l	b.d.l	101.95
13	c-47	41.98	61.45	b.d.l	b.d.l	b.d.l	103.43
14	c-47	41.79	60.1	b.d.l	b.d.l	b.d.l	101.89
15	c-47	42.14	62.87	b.d.l	b.d.l	b.d.l	105.01
16	c-47	43.03	62.35	b.d.l	b.d.l	b.d.l	108.2
17	c-47	42.18	59.72	b.d.l	b.d.l	b.d.l	101.9
18	c-47	41.37	60	b.d.l	b.d.l	b.d.l	104.1
19	c50	39.21	60.13	b.d.l	b.d.l	b.d.l	99.34
20	c50	40.29	58.9	b.d.l	b.d.l	b.d.l	99.19
21	c50	39.6	61.3	b.d.l	b.d.l	b.d.l	100.9
22	c50	40.2	59.82	b.d.l	b.d.l	b.d.l	102.73
23	c50	40.06	60.42	b.d.l	b.d.l	b.d.l	100.48
24	c50	41.14	58.88	b.d.l	b.d.l	b.d.l	103.44
25	c-52	44.09	64.4	b.d.l	b.d.l	b.d.l	112.55
26	c-52	40.14	61.71	b.d.l	b.d.l	b.d.l	101.85
27	c-52	40.95	62.34	b.d.l	b.d.l	b.d.l	103.29
28	c-52	41.08	62.98	b.d.l	b.d.l	b.d.l	104.06
29	c-52	40.5	62.21	b.d.l	b.d.l	b.d.l	102.71
30	c-24	42.93	61.26	b.d.l	0.71	b.d.l	107.65
31	c-24	42.55	61.31	b.d.l	0.59	b.d.l	107.03
32	c-24	41.62	59.7	b.d.l	1.15	b.d.l	102.47
33	c-35	42.47	61.08	b.d.l	0.48	b.d.l	106.61
34	c-49	42.6	59.75	b.d.l	0.7	b.d.l	103.05
35	c-52	41.46	59.66	4.29	0.88	b.d.l	106.29
36	C-12	39.78	60.49	b.d.l	b.d.l	b.d.l	100.27
37	C-12	39.12	63.55	b.d.l	b.d.l	b.d.l	102.67
38	c-16	39.37	60.27	b.d.l	b.d.l	b.d.l	99.64
39	c-16	40.37	61.56	b.d.l	b.d.l	b.d.l	101.93
40	c-16	37.86	58.45	b.d.l	b.d.l	b.d.l	96.31
41	c-16	36.93	60.55	b.d.l	b.d.l	b.d.l	97.48
42	c-16	38.63	58.92	b.d.l	b.d.l	b.d.l	97.55
43	c-21	39.91	59.63	b.d.l	b.d.l	b.d.l	99.54

Table A4.1 SEM EDS Analytical report - pyrrhotite mineral raw data

Point_ID	Sample	S K	Fe K	Pt M	Ni K	Cr K	Total
44	c-21	40.28	59.76	b.d.l	b.d.l	b.d.l	100.04
45	c-21	40.51	58.93	b.d.l	b.d.l	b.d.l	99.44
46	c-21	42.85	58.33	b.d.l	b.d.l	b.d.l	101.18
47	c-21	40.35	61.81	b.d.l	b.d.l	b.d.l	102.16
48	c-21	41.05	57.18	b.d.l	b.d.l	b.d.l	98.23
49	c-21	41.52	57.27	b.d.l	b.d.l	b.d.l	98.79
50	c-21	41.52	57.27	b.d.l	b.d.l	b.d.l	98.79
51	c-26	39.04	58.44	b.d.l	b.d.l	b.d.l	97.48
52	c-27	40.05	59.34	b.d.l	b.d.l	b.d.l	99.39
53	c-27	41.99	62.95	b.d.l	b.d.l	b.d.l	104.94
54	c-37	42.15	59.17	b.d.l	b.d.l	b.d.l	101.32
55	c-37	41.03	59.76	b.d.l	b.d.l	b.d.l	100.79
56	c-37	40.95	56.8	b.d.l	b.d.l	b.d.l	97.75
57	c-37	42.93	59.21	b.d.l	b.d.l	b.d.l	102.14
58	c-45	35.84	65.11	b.d.l	b.d.l	b.d.l	100.95
59	c-10	39.88	65.29	b.d.l	b.d.l	b.d.l	105.17
60	c-20	40.96	61.96	b.d.l	b.d.l	b.d.l	102.92
61	c-20	39.14	57.35	b.d.l	b.d.l	b.d.l	96.49
62	c-20	40.07	59.83	b.d.l	b.d.l	b.d.l	99.9
63	c-20	39.35	63.5	b.d.l	b.d.l	b.d.l	102.85
64	c-20	40.55	63.29	b.d.l	b.d.l	b.d.l	103.84
65	c-20	40.22	57.54	b.d.l	b.d.l	b.d.l	97.76
66	c-20	39.83	63.03	b.d.l	b.d.l	b.d.l	102.86
67	c-28	33.01	59.9	b.d.l	b.d.l	3.14	96.05
68	c-28	34.66	51.96	b.d.l	b.d.l	0.62	87.24
69	c-28	40.32	61.87	b.d.l	b.d.l	b.d.l	102.19
70	c-28	39.72	60.61	b.d.l	b.d.l	b.d.l	100.33
71	c-28	39.31	60.11	b.d.l	b.d.l	b.d.l	99.42
72	c-28	41.05	62.68	b.d.l	b.d.l	b.d.l	103.73
73	c-28	40.48	64.57	b.d.l	b.d.l	b.d.l	105.05
74	c-28	37.72	58.9	b.d.l	b.d.l	b.d.l	96.62
75	c-28	38.44	59.46	b.d.l	b.d.l	b.d.l	97.9
76	c-28	37.98	60.68	b.d.l	b.d.l	b.d.l	98.66
77	c-28	40.02	61.52	b.d.l	b.d.l	b.d.l	101.54
78	c-28	40.87	63.67	b.d.l	b.d.l	0.54	105.08
79	c-18	39.84	62.33	b.d.l	b.d.l	b.d.l	102.17
80	c-18	41.75	59.58	b.d.l	b.d.l	b.d.l	101.33
81	c-18	40.84	58.78	b.d.l	b.d.l	1.81	101.43
82	c-18	41.76	61.24	b.d.l	b.d.l	b.d.l	103
83	c-18	40.4	59.41	b.d.l	b.d.l	b.d.l	99.81
84	c-18	41.65	60.74	b.d.l	b.d.l	2.89	105.28
85	c-18	39.51	59.52	b.d.l	b.d.l	b.d.l	99.03
86	c-18	38.46	65.2	b.d.l	b.d.l	b.d.l	103.66

Table A4.1 SEM EDS Analytical report - pyrrhotite mineral raw data

Point_ID	Sample	S K	Fe K	O K	Pt M	Ni K	Cr K	Total
87	c-18	40.41	59.62	b.d.l	b.d.l	b.d.l	b.d.l	100.03
88	c-18	39.99	59.78	b.d.l	b.d.l	b.d.l	b.d.l	99.77
89	c-18	38.73	58.62	b.d.l	b.d.l	b.d.l	b.d.l	97.35
90	c-18	37.61	58.73	b.d.l	b.d.l	b.d.l	b.d.l	96.34
91	c-18	39.08	58.41	b.d.l	b.d.l	b.d.l	b.d.l	97.49
92	c-18	38.95	57.82	b.d.l	b.d.l	b.d.l	b.d.l	96.77
93	c-18	38.7	62.78	b.d.l	b.d.l	b.d.l	b.d.l	101.48
94	c-18	41.61	58.55	b.d.l	b.d.l	b.d.l	b.d.l	100.16
95	c-18	36.68	59.48	b.d.l	b.d.l	b.d.l	b.d.l	96.16
96	c-18	40.92	60.89	b.d.l	b.d.l	b.d.l	b.d.l	101.81
97	c-18	40.03	59.57	b.d.l	b.d.l	b.d.l	b.d.l	99.6

Table A4.2 SEM EDS Analytical report - pentlandite mineral raw data

Point_ID	Sample	S K	Fe K	Ni K	Zr L	Pt M	Co K	Cr K	Total
1	c-36	37.34	32.3	33.47	2.51	b.d.l	b.d.l	b.d.l	105.62
2	c-24	35.96	33.1	1	`	b.d.l	b.d.l	b.d.l	103.63
3	c-24	35.36	30.54	36.33	b.d.l	3.33	b.d.l	b.d.l	105.56
4	c-24	35.53	30.45	35.87	b.d.l	3.21	b.d.l	b.d.l	105.06
5	c-24	32.22	29.69	34.2	b.d.l	b.d.l	b.d.l	b.d.l	96.11
6	c-35	36.38	31.9	36.34	2.24	b.d.l	b.d.l	b.d.l	108.9
7	c-35	34.48	30.73	35.89	b.d.l	b.d.l	b.d.l	b.d.l	101.1
8	c-35	33.9	31.36	33.79	b.d.l	b.d.l	b.d.l	b.d.l	99.05
9	c-36	33.57	30.06	36.16	b.d.l	b.d.l	b.d.l	b.d.l	99.79
10	c-36	33.59	30.65	35.8	b.d.l	b.d.l	b.d.l	b.d.l	100.04
11	c-47	36.3	31.76	34.26	b.d.l	b.d.l	b.d.l	b.d.l	102.32
12	c-47	35.58	32.71	33.67	b.d.l	b.d.l	b.d.l	b.d.l	101.96
13	c-47	37.73	33.14	34.23	b.d.l	3.2	b.d.l	b.d.l	108.3
14	c-47	34.82	31.79	34.52	b.d.l	b.d.l	b.d.l	b.d.l	101.13
15	c-47	35.5	33.05	33.97	b.d.l	b.d.l	b.d.l	b.d.l	102.52
16	c-47	35.15	31.64	33.85	b.d.l	b.d.l	b.d.l	b.d.l	100.64
17	c-49	36.76	30.62	34.25	2.17	b.d.l	b.d.l	b.d.l	106.38
18	c-49	35.71	29.01	35.26	b.d.l	b.d.l	1.68	b.d.l	101.66
19	c-50	35.31	33.3	32.05	b.d.l	b.d.l	b.d.l	b.d.l	100.66
20	c-50	34.08	31.47	33.32	3.05	b.d.l	b.d.l	b.d.l	101.92
21	c-50	35.85	35.35	28.56	b.d.l	b.d.l	b.d.l	b.d.l	99.76
22	c-50	34.84	30.98	33.71	2.04	b.d.l	b.d.l	b.d.l	101.57
23	c-52	34.72	32.25	35.61	b.d.l	b.d.l	b.d.l	b.d.l	102.58
24	c-52	35.63	34.19	33.9	b.d.l	b.d.l	b.d.l	b.d.l	103.72
25	c-52	34.16	31.25	32.54	b.d.l	b.d.l	b.d.l	b.d.l	97.95
26	c-52	34.57	30.3	35.67	b.d.l	b.d.l	b.d.l	b.d.l	100.54
27	c-16	33.28	31.88	34.76	b.d.l	b.d.l	b.d.l	b.d.l	99.92
28	c-21	33.19	32.13	36.06	b.d.l	b.d.l	b.d.l	b.d.l	101.38
29	c-21	33.96	31.02	34.15	b.d.l	b.d.l	b.d.l	b.d.l	99.13
30	c-21	34.1	30.21	34.74	b.d.l	b.d.l	b.d.l	b.d.l	99.05
31	c-21	34.48	28.59	33.06	b.d.l	b.d.l	b.d.l	b.d.l	96.13
32	c-21	36.53	32.01	26.64	b.d.l	b.d.l	b.d.l	b.d.l	95.18
33	c-21	36.81	40.64	25.08	b.d.l	b.d.l	b.d.l	b.d.l	102.53
34	c-26	34.09	29.74	31.5	b.d.l	b.d.l	b.d.l	b.d.l	95.33
35	c-26	34.17	33.29	31.79	b.d.l	b.d.l	b.d.l	b.d.l	99.25
36	c-27	35.19	32.15	33.57	b.d.l	b.d.l	b.d.l	b.d.l	100.91
37	c-27	33.14	29.05	33.33	b.d.l	b.d.l	b.d.l	b.d.l	95.52
38	c-27	34.43	29.73	34.77	b.d.l	b.d.l	b.d.l	b.d.l	98.93
39	c-27	35.02	31.64	33.84	b.d.l	b.d.l	b.d.l	b.d.l	100.5
40	c-27	33.73	29.49	35.43	b.d.l	b.d.l	b.d.l	b.d.l	98.65
41	c-27	33.58	30.18	37.04	b.d.l	b.d.l	b.d.l	b.d.l	100.8
42	c-27	33.73	31.26	34.19	b.d.l	b.d.l	b.d.l	b.d.l	99.18
43	c-27	37.47	30.37	35.56	b.d.l	b.d.l	b.d.l	b.d.l	103.4

Table A4.2 SEM EDS Analytical report - pentlandite mineral raw data

Point_ID	Sample	S K	Fe K	Ni K	Zr L	Pt M	Co K	Cr K	total
44	c-27	33.2	29.63	34.7	b.d.l	b.d.l	b.d.l	b.d.l	97.53
45	c-37	36.66	33.18	32.52	b.d.l	b.d.l	b.d.l	b.d.l	102.36
46	c-37	34.84	30.47	34.11	b.d.l	b.d.l	b.d.l	b.d.l	99.42
47	c-37	36.18	29.48	34.33	b.d.l	b.d.l	b.d.l	b.d.l	99.99
48	c-37	35.08	32.76	31.69	b.d.l	b.d.l	b.d.l	b.d.l	99.53
49	c-37	34.58	32.15	32.05	b.d.l	b.d.l	b.d.l	b.d.l	98.78
50	c-37	33.61	32.14	33.25	b.d.l	b.d.l	b.d.l	b.d.l	99
51	c-45	33.21	32.8	31.33	b.d.l	b.d.l	b.d.l	b.d.l	97.34
52	c-45	32.7	33.99	31.26	b.d.l	b.d.l	b.d.l	b.d.l	97.95
53	c-45	33.32	33.86	30.78	b.d.l	b.d.l	b.d.l	b.d.l	97.96
54	c-45	32.9	32.77	31.55	b.d.l	b.d.l	b.d.l	b.d.l	97.22
55	c-10	34.26	30.49	31.9	b.d.l	b.d.l	b.d.l	b.d.l	96.65
56	c-10	34.53	35.16	33.28	b.d.l	b.d.l	b.d.l	b.d.l	102.97
57	c-10	32.16	35.62	29.09	b.d.l	b.d.l	b.d.l	b.d.l	96.87
58	c-10	33.5	33.33	32.36	b.d.l	b.d.l	b.d.l	b.d.l	99.19
59	c-10	33.56	31.53	31.47	b.d.l	b.d.l	b.d.l	b.d.l	96.56
60	c-10	32.35	30.07	30.99	b.d.l	b.d.l	b.d.l	b.d.l	93.41
61	c-10	34.81	32.81	37.32	b.d.l	b.d.l	b.d.l	b.d.l	104.94
62	c-10	30.95	33.04	30.46	b.d.l	b.d.l	b.d.l	b.d.l	94.45
63	c-10	33.34	31.61	31.59	b.d.l	b.d.l	b.d.l	b.d.l	96.54
64	c-10	33.5	33.64	32.57	b.d.l	b.d.l	b.d.l	b.d.l	99.71
65	c-10	34.53	34.58	33.45	b.d.l	b.d.l	b.d.l	b.d.l	105.31
66	c-20	34.49	32.98	33.66	b.d.l	b.d.l	b.d.l	b.d.l	101.13
67	c-20	35.21	31.81	35.43	b.d.l	b.d.l	b.d.l	b.d.l	102.45
68	c-20	34.52	31.22	32.36	b.d.l	b.d.l	b.d.l	b.d.l	98.1
69	c-20	35.54	32.63	33.66	b.d.l	b.d.l	b.d.l	b.d.l	101.83
70	c-20	34.52	31.42	35.77	b.d.l	b.d.l	b.d.l	b.d.l	101.71
71	c-28	34.95	31.66	35.15	b.d.l	b.d.l	b.d.l	1.31	103.07
72	c-28	35.26	33.92	35.44	b.d.l	b.d.l	b.d.l	b.d.l	104.62
73	c-28	32.64	36.11	24.56	b.d.l	b.d.l	b.d.l	1.82	95.13
74	c-28	31.89	34.23	31.91	b.d.l	b.d.l	b.d.l	1.6	99.63
75	c-28	32.84	28.89	34.1	b.d.l	b.d.l	b.d.l	b.d.l	95.83
76	c-28	33.58	30.57	33.73	b.d.l	b.d.l	b.d.l	b.d.l	97.88
77	c-18	35.5	32.28	34.51	b.d.l	b.d.l	b.d.l	b.d.l	102.29
78	c-18	34.1	30.48	33.95	b.d.l	b.d.l	b.d.l	b.d.l	98.53
79	c-18	34.65	32.91	32.44	b.d.l	b.d.l	b.d.l	b.d.l	100
80	c-18	34.88	32.7	34.97	b.d.l	b.d.l	b.d.l	b.d.l	102.55
81	c-18	35.83	36.17	25.13	b.d.l	b.d.l	b.d.l	b.d.l	97.13
82	c-18	33.67	32.74	32.67	b.d.l	b.d.l	b.d.l	b.d.l	99.08
83	c-18	33.74	30.56	31.68	b.d.l	b.d.l	b.d.l	b.d.l	95.98
84	c-18	34.37	31.62	31.71	b.d.l	b.d.l	b.d.l	b.d.l	97.7
85	c-18	33.21	29.15	34.54	b.d.l	b.d.l	b.d.l	b.d.l	96.9
86	c-18	35.87	28.16	33.19	b.d.l	b.d.l	b.d.l	b.d.l	97.22

Table A4.3 SEM EDS Analytical report - sulpharsenide (gersdorffite and cobaltite) mineral raw data

Point_ID	Sample	S K	Fe K	Co K	Ni K	As L	Pt M	Zn K	Cd L	Mn K	Cr K	Total
1	C-14	20.12	5.53	4.34	27.96	41.84	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.79
2	C-14	19.91	6.44	4.9	26.16	42.06	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.47
3	C-14	20.73	7.31	8.03	23.58	42.65	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.3
4	C-14	20.69	8.02	9.34	21.34	41.29	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.68
5	C-14	20.18	4.64	4.14	28.85	42.03	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.84
6	C-14	19.69	5.72	4.62	26.74	41.31	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.08
7	C-14	19.97	5.62	4.49	28.33	42.67	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.08
8	C-14	20.28	5.83	4.79	27.54	41.74	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.18
9	C-14	20.43	6.16	5.34	26.77	42.32	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.02
10	C-14	21	8.71	9.93	19.82	40.68	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.14
11	C-14	21.06	8.16	9.85	19.67	40.06	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.8
12	C-14	20.94	8.12	10.62	19.57	40.22	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.47
13	C-14	20.02	5.75	5.32	26.79	41.27	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.15
14	C-14	20.05	5.63	4.76	27.08	41.56	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.08
15	C-14	20.32	5.67	4.65	27.55	41.6	2.01	b.d.l	b.d.l	b.d.l	b.d.l	101.8
16	C-14	21.11	8.38	10.91	18.66	40.27	2.02	b.d.l	b.d.l	b.d.l	b.d.l	101.35
17	C-14	20.23	6.28	5.56	25.97	41.72	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.76
18	C-03	22.15	6.23	3.76	25.62	43.55	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.31
19	C-03	22.31	6.77	4.68	24.62	43.32	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.7
20	C-03	22.6	6.97	3.5	25.29	41.65	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.01
21	C-03	22.17	6.37	4	26.03	43.59	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.16
22	C-03	21.76	6.49	4.38	24	42.24	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.87
23	C-29	21.92	6.62	4.57	26.33	43	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.44
24	C-29	22.02	6.01	4.12	27.16	43.34	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.65
25	C-29	21.48	5.91	3.75	28.33	43.46	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.93
26	C-29	21.97	5.7	3.93	27.48	43.37	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.45
27	C-29	21.5	8.92	6.15	23.14	42.72	b.d.l	b.d.l	b.d.l	b.d.l	0.13	102.56
28	C-52	20.64	6.87	6.95	22.84	42.18	2.17	b.d.l	b.d.l	b.d.l	b.d.l	101.65
29	C-52	21.25	6.98	6.07	25.02	43.42	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.74
30	C-52	20.73	6.48	5.1	26.2	42.81	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.32
31	C-52	20.99	6.84	6.31	24.32	42.52	b.d.l	b.d.l	b.d.l	b.d.l	0.25	101.23
32	C-52	20.47	8.91	8.9	19.21	42.06	b.d.l	b.d.l	b.d.l	b.d.l	2.02	101.57
33	C-52	20.15	6.99	5.69	24.76	43.33	b.d.l	b.d.l	b.d.l	b.d.l	1.68	102.6
34	C-52	20.58	6.28	4.76	25.91	42.44	2.14	b.d.l	b.d.l	b.d.l	b.d.l	102.11
35	C-52	20.75	7.89	7.75	21.13	42.36	b.d.l	b.d.l	b.d.l	b.d.l	0.39	100.27
36	C-52	20.94	7.05	6.76	23.58	42.53	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.86
37	C-52	19.92	5.99	4.52	26.32	42.01	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.76
38	C-52	21.01	6.37	4.87	26.66	43.42	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.33
39	C-52	20.38	6.35	5.06	25.5	41.89	1.87	b.d.l	b.d.l	b.d.l	b.d.l	101.05
40	C-52	20.6	6.54	20.95	9.99	39.95	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.03
41	C-52	21.11	6.53	23.63	8.29	41.54	b.d.l	b.d.l	b.d.l	b.d.l	0.31	101.41
42	C-52	20.12	5.97	4.41	26.41	42.75	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.66
43	C-52	21.44	5.13	23.99	9.21	41.24	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.01

Table A4.3 SEM EDS Analytical report - sulpharsenide (gersdorffite and cobaltite) mineral raw data

Point_ID	Sample	S K	Fe K	Co K	Ni K	As L	Pt M	Zn K	Cd L	Mn K	Cr K	Total
44	C-52	20.86	6.51	5.65	25.08	42.5	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.6
45	C-52	20.9	5.41	21.15	10.8	40.77	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.03
46	C-52	20.51	6.9	5.5	24.79	42.61	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.31
47	C-52	21.18	7.33	6.66	22.66	42.46	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.29
48	C-52	20.62	6.97	7.18	22.65	41.78	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.2
49	C-52	20.82	7.05	6.91	22.92	41.68	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.38
50	C-52	20.52	6.82	6.06	24.11	43.09	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.6
51	C-52	20.5	6.11	5.24	25.64	43.24	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.73
52	C-52	20.08	6.42	5.52	24.39	41.47	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.88
53	C-52	21.5	5.03	23.44	8.92	41.11	1.91	b.d.l	b.d.l	b.d.l	b.d.l	101.91
54	C-52	20.87	5.91	20.93	10.28	41.08	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.07
55	C-52	20.81	6.32	4.96	26.24	43.06	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.39
56	C-35	19.92	7.1	5.76	24.28	43.18	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.24
57	C-35	19.88	6.92	5.87	24.25	44.42	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.34
58	C-35	20.43	6.28	5.46	25.22	44.02	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.41
59	C-35	19.97	6.5	5.64	24.17	43.99	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.27
60	C-35	19.63	6.33	4.99	23.58	44.12	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.65
61	C-35	20.2	6.72	5.56	23.21	43.74	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.43
62	C-35	19.81	5.97	4.9	26.34	44.44	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.46
63	C-35	19.81	6.2	5.46	25.59	44.78	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.84
64	C-35	20.08	6.59	5.44	23.66	43.75	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.52
65	C-35	20.06	6.1	4.83	25.83	43.96	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.78
66	C-35	18.92	6.31	4.76	25.84	42.94	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.77
67	C-35	19.79	6.61	5.37	25.46	44.32	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.55
68	C-35	19.94	6.4	5.5	25.32	44.26	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.42
69	C-35	20.06	7.02	4.53	25.61	44.48	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.7
70	C-35	19.51	6.86	5.7	24.53	44.01	b.d.l	b.d.l	b.d.l	b.d.l	0.19	100.8
71	C-35	19.59	6.64	5.18	25.68	44.12	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.21
72	C-35	19.11	6.17	6.63	23.49	44.15	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.55
73	C-35	19.9	6.44	4.96	25.5	44.31	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.11
74	C-35	20.01	6.22	4.83	26.06	44.45	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.57
75	C-35	20.37	6.3	5.48	25.05	43.82	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.02
76	C-35	20.75	7.59	7.19	22.2	42.55	2.1	b.d.l	b.d.l	b.d.l	b.d.l	102.38
77	C-35	21.66	7.53	17.22	13.68	41.87	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.96
78	C-35	20.04	7.66	7.78	20.65	42.33	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.46
79	C-35	21.96	7.2	18.57	11.3	40.46	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.49
80	C-35	20.43	6.57	6.57	24.17	44.37	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.11
81	C-35	20.98	7.49	11.24	18.11	43.72	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.54
82	C-36	18.39	6.12	4.35	26.54	43.55	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.95
83	C-36	20.44	7.47	9.86	20.16	43.78	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.71
84	C-36	20.24	7.53	10.1	19.73	43.96	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.56
85	C-36	19.94	6.2	5.12	26.35	45.26	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.87
86	C-36	19.86	6.31	5.93	24.72	44.61	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.43

Table A4.3 SEM EDS Analytical report - sulpharsenide (gersdorffite and cobaltite) mineral raw data

Point_ID	Sample	S K	Fe K	Co K	Ni K	As L	Pt M	Zn K	Cd L	Mn K	Cr K	Total
87	C-36	20.74	4.69	19.46	12.79	43.64	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.32
88	C-36	19.34	6.34	5.72	25.19	43.25	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.84
89	C-36	20.93	6.61	22.46	9.21	43.66	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.87
90	C-36	19.97	7.01	7.32	22.88	44.53	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.71
91	C-36	20.96	6.22	21.19	10.69	43.7	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.76
92	C-36	20.12	7.53	13.06	16.56	44.16	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.43
93	C-36	20.28	7.48	7.68	22.15	43.87	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.46
94	C-36	20.91	6.72	18.36	13.45	43.38	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.82
95	C-36	20.23	7.2	10.78	19.61	44.44	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.26
96	C-36	20.63	7.38	19.44	11.54	42.05	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.04
97	C-36	20.94	7.55	14.11	16.55	42.04	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.19
98	C-36	20.02	6.7	5.64	24.5	44.33	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.19
99	C-36	20.7	5.88	19.9	12.08	44.06	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.62
100	C-36	20.02	5.81	4.7	26.63	45.34	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.5
101	C-50	20.99	6.76	6.64	23.58	42.86	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.83
102	C-50	20.5	6.87	5.87	23.77	42.26	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.27
103	C-50	20.36	6.22	5.14	25.29	42.15	1.84	b.d.l	b.d.l	b.d.l	b.d.l	101
104	C-50	20.17	6.74	6.15	23.89	41.97	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.92
105	C-50	20.62	7.21	7.75	21.84	41.55	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.97
106	C-50	20.38	6.34	5.3	25.18	42.21	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.41
107	C-50	20.35	6.97	6.46	23.47	42.32	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.57
108	C-50	20.66	8.31	7.72	20.73	42.33	b.d.l	b.d.l	b.d.l	b.d.l	0.21	99.96
109	C-50	20.49	6.51	5.7	24.26	42.08	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.04
110	C-50	20.83	6.33	5.34	25.27	42.98	2.08	b.d.l	b.d.l	b.d.l	b.d.l	102.83
111	C-50	20.62	6.53	6.17	24.28	42.24	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.84
112	C-50	20.55	6.2	5.69	25.25	42.83	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.52
113	C-50	20.62	6.58	6.03	24.42	42.21	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.86
114	C-50	20.41	6.19	5.38	25.65	42.47	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.1
115	C-50	20.59	6.28	5.23	25.24	42.5	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.84
116	C-50	20.18	5.66	3.19	27.73	42.31	1.94	b.d.l	b.d.l	b.d.l	b.d.l	101.01
117	C-50	20.7	6.91	6.49	23.63	42.14	2	b.d.l	b.d.l	b.d.l	b.d.l	101.87
118	C-50	20.59	6.48	5.67	24.63	42.28	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.65
119	C-50	20.66	6.91	7.79	22	41.21	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.57
120	C-24	21	6.44	5.28	26.4	43.47	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.59
121	C-24	20.97	6.74	5.7	26.02	43.32	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.75
122	C-24	21.03	6.82	5.39	25.92	43.17	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.33
123	C-24	20.98	6.42	5.27	26.52	43.33	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.52
124	C-24	20.8	6.19	4.97	27.22	43.32	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.5
125	C-24	20.75	6.32	5.25	26.19	43.31	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.82
126	C-24	20.71	6.26	5.45	25.75	42.13	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.3
127	C-24	20.67	6.78	5.48	25.7	43.17	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.8
128	C-24	21.05	6.96	5.93	25.23	43.65	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.82
129	C-24	20.94	6.16	4.93	26.56	43.66	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.25

Table A4.3 SEM EDS Analytical report - sulpharsenide (gersdorffite and cobaltite) mineral raw data

Point_ID	Sample	S K	Fe K	Co K	Ni K	As L	Pt M	Zn K	Cd L	Mn K	Cr K	Total
130	C-24	20.81	6.97	6.14	24.47	42.7	b.d.l	b.d.l	b.d.l	b.d.l	0.28	101.37
131	C-24	21.08	6.58	6.05	24.61	43.8	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.12
132	C-24	20.79	6.31	5.16	26.74	43.42	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.42
133	C-24	20.83	5.77	4.64	27.3	43.19	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.73
134	C-24	21.07	7.35	7.53	22.93	43.01	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.89
135	C-24	20.53	6.54	6.1	23.17	41.17	2.35	b.d.l	b.d.l	b.d.l	b.d.l	99.86
136	C-24	20.64	6.66	5.5	25.88	42.34	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.02
137	C-24	20.59	7.13	5.86	24.37	42.06	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.01
138	C-24	20.92	7.03	6.47	24.32	42.79	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.53
139	C-24	21.16	7.03	6.3	24.44	43.23	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.16
140	C-24	21.23	8.48	8.01	20.89	42.41	b.d.l	b.d.l	b.d.l	b.d.l	1.28	102.3
141	C-47	21.33	6.41	3.93	25.95	41.99	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.61
142	C-47	20.96	5.54	2.71	28.34	43.07	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.62
143	C-47	21.06	5.63	2.51	27.53	42.72	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.45
144	C-47	21.62	5.18	2.92	28.85	44.01	b.d.l	b.d.l	b.d.l	b.d.l	0.23	102.81
145	C-47	21.85	5.97	3.48	27.1	43.19	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.59
146	C-47	20.73	4.8	2.38	29.13	43.59	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.63
147	C-47	20.92	5.25	2.3	28.76	42.73	1.87	b.d.l	b.d.l	b.d.l	0.24	102.07
148	C-47	20.98	5.09	2.36	28.9	43.18	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.51
149	C-47	21.08	5.37	2.37	27.75	43.16	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.73
150	C-47	20.83	6.54	2.98	27.77	43.89	b.d.l	b.d.l	b.d.l	b.d.l	0.39	102.4
151	C-47	21.25	5.73	3.02	27.11	42.45	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.56
152	C-47	21.16	6.07	3.23	26.76	42.31	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.53
153	C-47	21.24	5.5	2.88	27.74	42.44	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.8
154	C-47	21.3	5.58	1.89	28.49	42.49	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.75
155	C-47	20.96	5.61	2.68	27.75	42.4	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.4
156	C-47	21.12	5.47	3.44	27.29	42.48	2.1	b.d.l	b.d.l	b.d.l	b.d.l	101.9
157	C-47	21.29	5.98	3.62	27.14	42.67	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.7
158	C-47	20.92	5.49	2.77	28.29	42.58	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.05
159	C-49	21.09	6.77	7.89	22.58	42.49	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.82
160	C-49	21.17	6.38	6.48	23.85	42.49	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.37
161	C-49	21.18	6.44	5.81	24.4	42.63	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.46
162	C-49	20.92	6.79	6.81	23.14	41.84	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.5
163	C-49	21.33	7.52	8.18	22.07	42.72	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.82
164	C-49	20.38	7.17	6.84	24.29	41.82	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.5
165	C-49	21.76	6.81	5.88	24.91	43.42	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.78
166	C-49	21.69	7.25	6.87	23.09	42.74	b.d.l	b.d.l	b.d.l	b.d.l	1.02	102.66
167	C-49	21.68	6.15	4.8	26.69	43.62	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.94
168	C-49	21.49	6.37	4.98	26.01	43.3	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.15
169	C-49	21.33	6.23	5.79	25.99	43.49	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.83
170	C-49	21.53	6.42	6.15	24.85	43.49	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.44
171	C-49	21.32	6.44	6.3	23.94	42.56	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.56
172	C-49	21.14	6.04	5.08	25.49	42.6	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.35

Table A4.3 SEM EDS Analytical report - sulpharsenide (gersdorffite and cobaltite) mineral raw data

Point_ID	Sample	S K	Fe K	Co K	Ni K	As L	Pt M	Zn K	Cd L	Mn K	Cr K	Total
173	C-49	21.01	5.92	4.8	26.23	42.66	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.62
174	C-49	21	6.06	4.97	25.84	42.6	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.47
175	C-49	20.8	6.08	5.23	25.85	42.66	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.62
176	C-49	20.8	6.08	5.23	25.85	42.66	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.62
177	C-49	20.76	7.12	6.33	23.14	41.82	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.17
178	C-49	20.7	6.14	4.53	26.15	42.68	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.2
179	C-49	21.08	6.29	5.02	26.05	43	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.44
180	c-12	19.65	7.16	6.56	21.84	41.93	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.14
181	c-12	18.4	6.8	4.62	22.7	42.67	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	95.19
182	c-12	24.68	18.74	13.52	9	30.33	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	96.27
183	c-21	19.69	6.13	5.18	22.44	45.15	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.59
184	c-21	20.03	7.18	11.51	16.43	42.61	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.76
185	c-21	20.12	5.17	5.17	23.84	43.77	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.07
186	c-21	20.19	8.28	6.4	21.64	44.71	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.22
187	c-21	20.23	6.13	5.13	22.87	43.99	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.35
188	c-21	20.26	8.82	9.83	18.28	44.49	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.68
189	c-21	20.35	9.79	7.09	17.74	43.44	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.41
190	c-21	20.35	6.47	19.7	9.69	41.91	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.12
191	c-21	20.52	6.24	5.58	22.33	44.92	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.59
192	c-21	20.52	6.13	4.46	23.35	43.24	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.7
193	c-21	20.66	8.01	11.66	15.02	43.32	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.67
194	c-21	20.69	6.52	6.75	20.2	44.01	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.17
195	c-21	20.78	6.29	5.85	23.05	44.35	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.32
196	c-21	20.84	6.61	5.5	22.32	43.41	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.68
197	c-21	20.84	7.63	5.38	20.92	42.27	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.04
198	c-21	20.85	7.12	13.64	13.89	43.28	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.78
199	c-21	20.89	7.24	5.56	20.91	44.04	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.64
200	c-21	20.95	6.99	5.82	22.59	46.17	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.52
201	c-21	21.03	6.39	5.7	21.21	43.1	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.43
202	c-21	21.12	6.79	5.2	22.83	42.96	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.9
203	c-21	21.33	6.77	5.95	23.33	44.27	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.65
204	c-26	19.58	6.07	5.14	24.46	44.05	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.3
205	c-26	20.86	6.77	6.61	21.31	42.21	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.76
206	c-26	20.75	6.28	7.17	19.13	42.49	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	95.82
207	c-26	20.78	6.24	16.99	12.31	45.43	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.75
208	c-26	20.6	7.61	5.57	22.39	43.95	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.12
209	c-26	19.81	6.48	5.13	21.62	44.65	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.69
210	c-26	21.19	6.02	5.32	23.21	43.29	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.03
211	c-26	20.13	7.49	5.23	22.19	44.4	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.44
212	c-26	20.52	6.81	7.77	20.68	42.57	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.35
213	c-26	20.12	5.99	5.46	21.77	42.71	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	96.05
214	c-26	20.31	7.42	6.84	22.74	45.01	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.32
215	c-26	20.79	6.65	5.58	20.93	43.61	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.56

Table A4.3 SEM EDS Analytical report - sulpharsenide (gersdorffite and cobaltite) mineral raw data

Point_ID	Sample	S K	Fe K	Co K	Ni K	As L	Pt M	Zn K	Cd L	Mn K	Cr K	Total
216	c-26	19.13	6.89	7.09	22.15	42.73	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.99
217	c-26	20.17	6.76	6	23.15	44.55	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.63
218	c-26	19.31	5.25	4.59	23.94	46.26	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.35
219	c-26	18.93	6.35	4.06	24.25	45.01	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.6
220	c-26	20.78	6.58	4.35	25.27	43.71	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.69
221	c-26	18.71	5.87	3.41	24.79	44.28	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.06
222	c-26	20.28	5.91	3.93	23.91	44.24	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.27
223	c-27	20.86	7.77	17.22	11.54	43.83	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.22
224	c-27	19.79	6.42	6.01	21.75	42	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	95.97
225	c-27	21.41	7.77	7.11	21.45	44.79	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.53
226	c-27	20.68	5.88	8.93	20.35	44.53	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.37
227	c-27	21.64	5.9	21.33	9.16	44.1	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.13
228	c-27	20.83	5.52	20.29	9.34	44.46	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.44
229	c-27	22.51	5.45	21.6	7.35	40.56	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.47
230	c-27	20.29	6.13	4.04	26.45	42.62	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.53
231	c-27	21.65	7.46	4.5	23.47	48.52	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	105.6
232	c-27	19.51	5.58	4.51	24.1	41.74	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	95.44
233	c-27	22.98	6.42	16.84	12.33	46.8	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	105.37
234	c-27	22.5	6.89	15.62	12.12	44.12	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.25
235	c-27	20.49	6.99	6.87	22.62	43.98	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.95
236	c-27	20.66	6.03	4.9	22.77	41.18	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	95.54
237	c-27	21.14	6.29	5.69	25.84	45.69	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	104.65
238	c-27	20.94	6.9	4.92	25.56	45.36	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	103.68
239	c-27	19.83	6.79	6.14	23.15	44.11	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.02
240	c-27	21.25	6.22	4.84	25.47	44.97	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.75
241	c-27	20.64	7.75	7.37	19.66	41.92	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.34
242	c-27	20.15	7.89	7.62	19.63	44.67	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.96
243	c-27	23.97	5.08	17.98	5.63	30.99	b.d.l	9.92	3.64	1.53	b.d.l	93.57
244	c-37	20.65	6.52	4.56	24.33	46.07	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.13
245	c-37	21.48	4.8	3.61	22.81	45.58	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.28
246	c-37	20.65	5.74	4.86	23.65	45.23	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.13
247	c-37	20.92	6.01	4.03	24	46.16	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.12
248	c-37	20.86	6.7	4.36	23.47	45.61	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101
249	c-37	20.5	7.11	4.17	23.91	45.21	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.9
250	c-37	20.75	5.6	3.53	24.86	45.2	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.94
251	c-37	20.19	6.53	4.74	23.89	46.46	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.81
252	c-45	19.08	7.52	14.77	13.51	42.32	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.2
253	c-45	19.5	7.12	11.49	17.2	41.73	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.04
254	c-45	19.3	6.7	10.89	17.4	42.41	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	96.7
255	c-45	20.55	8.88	18.38	10.94	41.16	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.91
256	c-10	2.7	4.93		48.07	42.87	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.57
257	c-10	17.7	4.2	20.89	11.07	43.94	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.8
258	c-20	20.78	7.3	4.55	23.65	43.95	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.23

Table A4.3 SEM EDS Analytical report - sulpharsenide (gersdorffite and cobaltite) mineral raw data

Point_ID	Sample	S K	Fe K	Co K	Ni K	As L	Pt M	Zn K	Cd L	Mn K	Cr K	Total
259	c-20	22.43	6.82	21.03	9.27	40.75	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.3
260	c-20	20.21	6.03	4.75	22.04	42.54	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	95.57
261	c-20	20.47	5.98	4.75	24.18	42.32	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.7
262	c-20	22.19	9.04	21.11	8.15	39.59	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.08
263	c-20	21.74	7.36	6.12	21.76	44.31	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.29
264	c-20	20.05	6.58	5.36	23.16	42.1	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.25
265	c-20	26.51	28.07	10.37	5.97	31.63	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.55
266	c-20	22.37	13.55	12.96	13.7	40.87	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	103.45
267	c-20	20.03	9.47	16.32	9.51	41.21	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	96.54
268	c-20	20.44	8.3	7.83	21.42	44.41	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.4
269	c-20	21.03	11.52	15.84	8.14	38.69	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	95.22
270	c-20	21.47	5.79	5.1	26.89	43.81	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	103.06
271	c-20	21.24	8.83	7.73	21.64	45.95	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	105.39
272	c-20	20.06	6.33	4.69	23.91	45.33	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.32
273	c-20	20.53	8.53	8.91	17.22	40.62	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	95.81
274	c-20	20.67	6.13	6.7	21.66	41.75	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	96.91
275	c-20	20.04	7.49	9.43	20.49	41.58	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.03
276	c-20	19.82	8.02	6.66	20.42	44.82	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.74
277	c-20	19.77	6.41	6.25	25.29	44.05	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.77
278	c-20	26.52	17.52	19.13	5.32	37.68	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	106.17
279	c-20	20.9	6.55	5.68	22.16	41.5	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	96.79
280	c-20	22.61	12.77	15.99	8.87	40.31	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.55
281	c-28	19.62	6.9	3.53	24.22	43.17	b.d.l	b.d.l	b.d.l	b.d.l	0.59	98.03
282	c-28	19.98	5.26	4.41	24.92	44.17	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.74
283	c-28	21.04	5.68	3.33	24.04	44.76	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.85
284	c-28	20.21	5.96	3.89	25.01	43.46	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.53
285	c-28	19.73	5.95	3.53	25.06	43.85	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.12
286	c-28	20.55	7.09	4.68	25.62	43.5	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.44
287	c-28	19.85	7.93	4.26	23.05	42.99	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.08
288	c-28	20.36	7.55	6.53	20.96	43.36	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.76
289	c-28	24.36	18.92	11.07	11.17	34.61	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.13
290	c-28	19.43	6.06	3.97	24.91	44.16	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.53
291	c-28	22.49	6.13	2.78	26.71	43.23	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.34
292	c-28	20.89	6.17	4.1	26.65	46.18	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	103.99
293	c-28	19.95	6.82	5.17	22.77	42.01	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	96.72
294	c-28	19.89	6.72	5.61	24.04	43	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.26
295	c-28	19.95	6.66	5.4	23.64	42.83	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.48
296	c-28	19.93	7.89	7.37	22.34	43.26	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.79
297	c-18	20.71	7.86	7.34	20.79	43.83	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.53
298	c-18	20.85	8.87	5.8	21.29	43.16	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.97
299	c-18	20.73	7.62	11.23	16.48	44.33	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.39
300	c-18	20.5	6.8	6.49	22.12	43.64	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.55
301	c-18	19.89	7.76	6.99	20.91	42.29	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.84

Table A4.3 SEM EDS Analytical report - sulpharsenide (gersdorffite and cobaltite) mineral raw data

Point_ID	Sample	S K	Fe K	Co K	Ni K	As L	Pt M	Zn K	Cd L	Mn K	Cr K	Total
302	c-18	19.41	6.86	6.87	21.64	44.31	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.09
303	c-18	18.52	5.25	6.07	22.15	41.57	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	93.56
304	c-18	20.52	7.4	22.93	8.06	43.02	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.93
305	c-18	21.58	7.8	5.9	20.89	45.08	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.25
306	c-18	21.41	7.53	17.29	10.67	43.58	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.48
307	c-18	19.37	7.7	12.31	16.33	43	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.71
308	c-18	20.79	7.94	10.32	18.77	44.68	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.5
309	c-18	21.12	8.01	20.54	9.91	42.61	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.19
310	c-18	21.2	10.17	18.24	9.1	43.21	b.d.l	b.d.l	b.d.l	b.d.l	1.16	103.08
311	c-18	19.49	8.82	16.81	11.71	41.21	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.04
312	c-18	21.59	8.5	17.81	10.25	44.91	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	103.06
313	c-18	21.68	7.4	18.15	10.43	44.17	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.83
314	c-18	20.25	7.26	7.67	20.39	46.02	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.59
315	c-18	19.33	7.41	6.82	18.51	43.09	b.d.l	b.d.l	b.d.l	b.d.l	1.1	96.26
316	c-18	21.43	8.01	15.82	11.61	45.73	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.6
317	c-18	19.77	6.83	5.9	19.96	45.33	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.79
318	c-18	19.62	4.09	26.35	6.63	41.03	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.72
319	c-18	19.78	6.45	4.67	23.59	44.25	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.74
320	c-18	21.81	9.24	15.96	12.01	41.43	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.45
321	c-18	20.71	6.86	11.71	18.94	43.11	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.33
322	c-18	20.83	7.82	9.77	17.86	42.98	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.26
323	c-18	20.5	6.25	7.09	23.79	41.37	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99
324	c-18	20.41	8.01	8.01	17.19	43.6	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.22
325	c-18	21.14	8.58	8.12	18.26	42.13	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.23
326	c-18	20.33	7.98	7.89	21.17	44.51	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	101.88
327	c-18	19.36	6.26	5.03	23.43	43.92	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98
328	c-18	20.56	6.33	5.11	22.77	44.22	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.99
329	c-18	19.11	6.85	6.97	21.82	44.39	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	99.14
330	c-18	19.76	6.66	6.21	22.34	43.32	b.d.l	b.d.l	b.d.l	b.d.l	0.53	98.82
331	c-18	20.27	6.28	5.77	23.73	46.44	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	102.49
332	c-18	20.1	6.4	5.97	22.72	43.68	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	98.87
333	c-18	19.76	9.14	7.06	18.92	40.56	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	95.44
334	c-18	19.74	10.24	8.54	16.93	42.05	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.5
335	c-18	20.44	9.19	6.23	20.54	44.45	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	100.85
336	c-18	19.9	5.63	4.39	23.27	44.11	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	97.3

Table A4.4 SEM EDS Analytical report - chalcopyrite mineral raw data

Point_ID	Sample	S K	Cr K	Fe K	Cu K	Total
1	c-12	34.76	b.d.l	30.84	33.46	99.06
2	c-37	36.64	b.d.l	29.81	32	98.45
3	c-45	34.75	b.d.l	30.53	31.64	96.92
4	c-10	34.48	1.47	29.2	29.33	94.48
5	c-28	34.79	b.d.l	30.64	32.12	97.55

Table A4.5 SEM EDS Analytical report – magnetite mineral raw data (in veins)

Point_ID	Sample	O K	Al K	Ca K	Mg K	Cr K	Mn K	Fe K	Ni K	Co K	Total
1	c-47	28.23	0.39	0.39	b.d.l	b.d.l	b.d.l	68.74	0.62	b.d.l	98.37
2	c-35	33.17	b.d.l	b.d.l	3.47	0.42	5.99	66.08	b.d.l	0.52	109.65
3	c-45	32.31	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	71.58	b.d.l	b.d.l	103.89
4	c-45	32.77	b.d.l	b.d.l	b.d.l	b.d.l	1.27	71.32	b.d.l	b.d.l	105.36

Table A4.6 SEM EDS Analytical report – chromite/magnetite mineral raw data

Point_ID	Sample	O K	Ca K	Na K	Mg K	Al K	Ti K	Cr K	Mn K	Fe K	Zn K	S K	Ni K	total
1	c-29	23.70	b.d.l	b.d.l	1.03	0.87	0.24	5.67	0.35	65.24	b.d.l	b.d.l	b.d.l	97.10
2	c-35	27.55	b.d.l	b.d.l	4.34	b.d.l	0.22	8.28	0.34	61.48	b.d.l	b.d.l	b.d.l	102.21
3	c-35	31.07	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	6.72	1.50	61.55	b.d.l	b.d.l	b.d.l	100.84
4	c-35	27.37	b.d.l	0.28	b.d.l	0.48	0.17	28.04	0.92	43.71	0.76	b.d.l	b.d.l	101.73
5	c-35	31.53	5.98	b.d.l	b.d.l	0.61	b.d.l	27.13	2.21	30.86	0.49	b.d.l	b.d.l	98.81
6	c-35	28.93	1.41	0.30	1.49	b.d.l	0.24	34.37	3.95	29.01	0.71	b.d.l	b.d.l	100.41
7	c-35	29.34	b.d.l	b.d.l	3.23	b.d.l	0.55	7.16	1.05	61.98	b.d.l	b.d.l	b.d.l	103.31
8	c-36	31.12	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	5.69	b.d.l	66.85	b.d.l	b.d.l	b.d.l	103.66
9	c-36	25.13	b.d.l	b.d.l	5.94	1.05	b.d.l	b.d.l	6.85	60.03	b.d.l	b.d.l	b.d.l	99.00
10	c-47	24.64	b.d.l	b.d.l	3.98	1.85	b.d.l	10.85	b.d.l	55.51	b.d.l	b.d.l	b.d.l	96.83
11	c-47	24.98	b.d.l	b.d.l	5.38	1.62	0.49	10.22	b.d.l	56.02	b.d.l	b.d.l	b.d.l	98.71
12	c-47	26.03	b.d.l	b.d.l	6.12	2.27	0.53	12.47	0.44	54.72	b.d.l	b.d.l	b.d.l	102.58
13	c-47	25.86	b.d.l	b.d.l	3.88	1.56	0.49	9.47	b.d.l	57.86	b.d.l	b.d.l	b.d.l	99.12
14	c-47	25.87	b.d.l	b.d.l	6.77	1.16	0.96	7.00	b.d.l	58.91	b.d.l	b.d.l	b.d.l	100.67
15	c-47	23.82	b.d.l	b.d.l	4.79	1.55	0.74	8.78	b.d.l	57.24	b.d.l	b.d.l	b.d.l	96.92
16	c-47	24.74	b.d.l	b.d.l	7.87	1.01	0.75	8.17	0.86	57.01	b.d.l	b.d.l	b.d.l	100.41
17	c-47	25.38	b.d.l	b.d.l	3.12	0.82	0.56	7.88	b.d.l	58.27	b.d.l	b.d.l	b.d.l	96.03
18	c-49	24.23	b.d.l	b.d.l	0.99	3.23	0.33	31.04	1.02	34.76	1.12	b.d.l	b.d.l	96.72
19	c-12	30.79	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	23.63	b.d.l	41.84	b.d.l	b.d.l	b.d.l	96.26
20	c-12	33.88	b.d.l	b.d.l	8.09	b.d.l	b.d.l	23.10	b.d.l	39.85	b.d.l	b.d.l	b.d.l	104.92
21	c-12	30.86	b.d.l	b.d.l	9.73	b.d.l	b.d.l	22.15	b.d.l	38.90	b.d.l	b.d.l	b.d.l	101.64
22	c-10	33.35	b.d.l	b.d.l	10.40	4.16	b.d.l	30.82	b.d.l	22.25	1.58	b.d.l	b.d.l	102.56
23	c-10	33.16	b.d.l	b.d.l	6.19	0.47	0.88	19.85	b.d.l	43.35	b.d.l	b.d.l	b.d.l	103.90

Table A4.6 SEM EDS Analytical report - chromite/magnetite mineral raw data

Point_ID	Sample	O K	Ca K	Na K	Mg K	Al K	Ti K	Cr K	Mn K	Fe K	Zn K	S K	Ni K	total
24	c-10	32.62	b.d.l	b.d.l	6.62	0.84	0.62	23.72	1.09	35.90	b.d.l	b.d.l	b.d.l	101.41
25	c-20	13.46	b.d.l	b.d.l	b.d.l	2.85	b.d.l	15.14	7.78	39.70	b.d.l	18.21	b.d.l	97.14
26	c-20	33.05	b.d.l	b.d.l	b.d.l	1.79	b.d.l	29.20	b.d.l	34.24	b.d.l	b.d.l	b.d.l	98.28
27	c-20	33.05	b.d.l	b.d.l	b.d.l	1.79	b.d.l	29.20	b.d.l	34.24	b.d.l	b.d.l	b.d.l	98.28
28	c-20	34.12	b.d.l	b.d.l	b.d.l	1.99	b.d.l	29.29	b.d.l	34.94	1.62	b.d.l	b.d.l	101.96
29	c-28	32.42	b.d.l	b.d.l	b.d.l	1.34	b.d.l	14.31	b.d.l	46.24	b.d.l	b.d.l	b.d.l	94.31
30	c-28	31.91	b.d.l	b.d.l	b.d.l	1.47	b.d.l	17.14	b.d.l	43.60	b.d.l	b.d.l	b.d.l	94.12
31	c-28	30.37	b.d.l	b.d.l	3.28	1.05	0.85	17.28	0.61	40.67	b.d.l	b.d.l	b.d.l	94.11
32	c-28	34.56	b.d.l	b.d.l	b.d.l	1.27	0.88	19.24	b.d.l	45.48	b.d.l	b.d.l	b.d.l	101.43
33	c-28	31.90	b.d.l	b.d.l	5.31	1.06	0.78	15.84	b.d.l	45.90	b.d.l	b.d.l	b.d.l	100.79
34	c-28	32.56	b.d.l	b.d.l	6.31	b.d.l	0.84	17.16	b.d.l	41.08	b.d.l	b.d.l	b.d.l	97.95
35	c-28	33.81	b.d.l	b.d.l	b.d.l	2.37	b.d.l	18.42	b.d.l	43.77	b.d.l	b.d.l	b.d.l	98.37
36	c-28	33.15	b.d.l	b.d.l	b.d.l	2.13	b.d.l	18.44	b.d.l	43.56	b.d.l	b.d.l	b.d.l	97.28
37	c-28	33.09	b.d.l	b.d.l	7.13	1.92	0.82	15.77	b.d.l	41.89	b.d.l	b.d.l	b.d.l	100.62
38	c-28	31.57	b.d.l	b.d.l	6.04	1.39	1.14	19.64	0.92	40.68	b.d.l	b.d.l	b.d.l	101.38
39	c-28	29.23	b.d.l	b.d.l	6.28	1.59	0.68	21.06	1.01	36.60	b.d.l	b.d.l	b.d.l	96.45
40	c-28	34.85	b.d.l	b.d.l	b.d.l	1.86	b.d.l	38.85	b.d.l	25.34	b.d.l	b.d.l	b.d.l	100.90
41	c-28	31.57	b.d.l	b.d.l	b.d.l	2.94	b.d.l	15.82	b.d.l	48.89	b.d.l	b.d.l	b.d.l	99.22
42	c-28	29.94	b.d.l	b.d.l	b.d.l	1.97	b.d.l	13.32	b.d.l	51.48	b.d.l	b.d.l	b.d.l	96.71
43	c-28	33.35	b.d.l	b.d.l	12.28	6.83	0.56	18.56	0.82	30.24	b.d.l	b.d.l	b.d.l	102.64
44	c-28	31.50	b.d.l	b.d.l	9.70	4.97	b.d.l	13.76	b.d.l	40.82	b.d.l	b.d.l	b.d.l	100.75
45	c-28	24.29	b.d.l	b.d.l	11.29	2.63	b.d.l	36.04	b.d.l	24.93	b.d.l	b.d.l	b.d.l	99.18
46	c-28	31.99	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	37.87	b.d.l	26.48	b.d.l	b.d.l	b.d.l	96.34

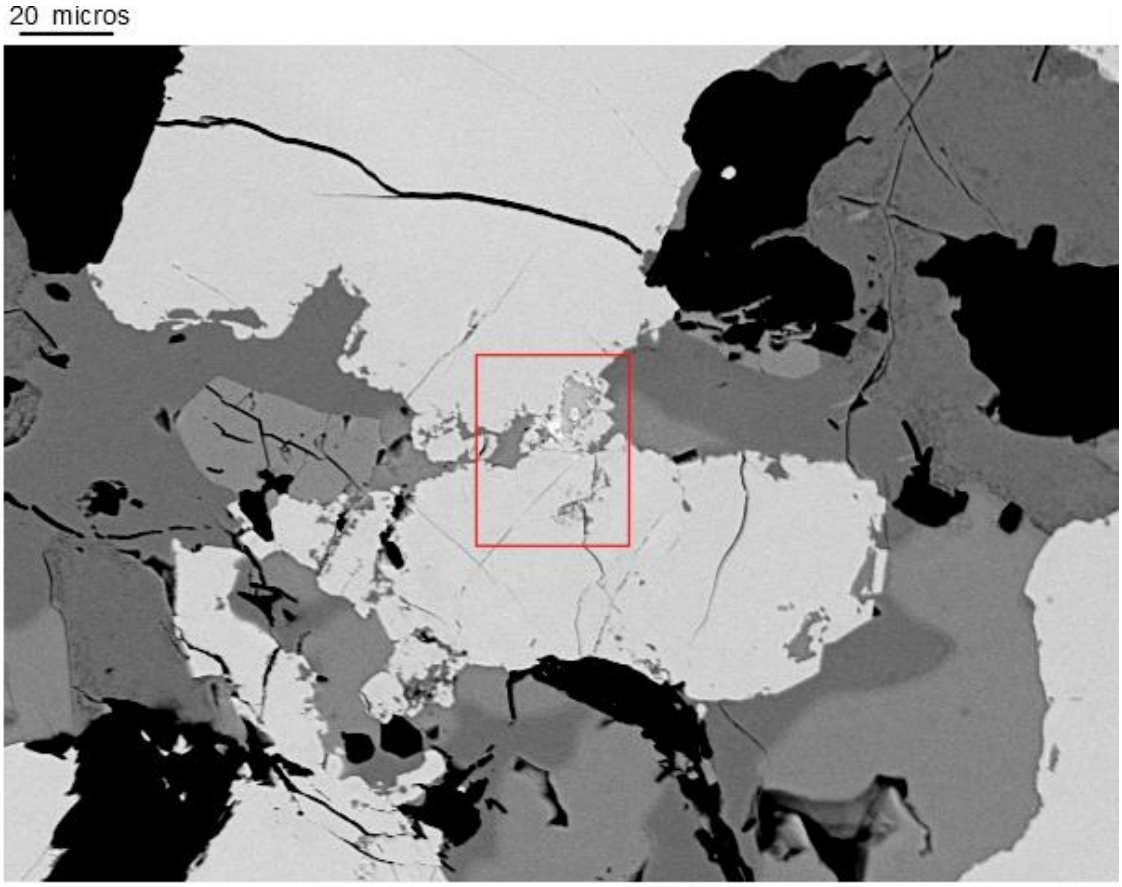
Table A4.6 SEM EDS Analytical report - chromite/magnetite mineral raw data

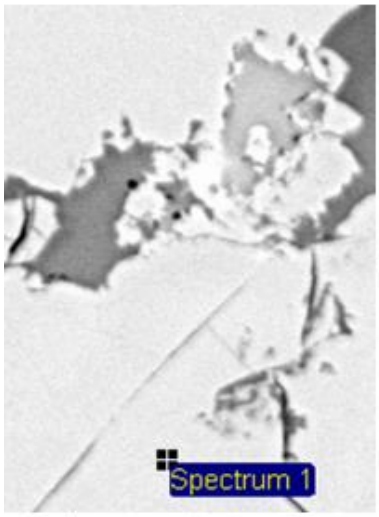
Point_ID	Sample	O K	Ca K	Na K	Mg K	Al K	Ti K	Cr K	Mn K	Fe K	Zn K	S K	Ni K	total
47	c-28	32.57	b.d.l	b.d.l	8.15	b.d.l	b.d.l	37.32	b.d.l	24.29	b.d.l	b.d.l	b.d.l	102.33
48	c-28	32.53	b.d.l	b.d.l	b.d.l	2.45	b.d.l	16.29	b.d.l	46.46	b.d.l	b.d.l	b.d.l	97.73
49	c-28	31.27	b.d.l	b.d.l	b.d.l	3.33	b.d.l	16.43	b.d.l	48.06	b.d.l	b.d.l	b.d.l	99.09
50	c-28	31.80	b.d.l	b.d.l	b.d.l	2.96	b.d.l	17.16	b.d.l	46.63	b.d.l	b.d.l	b.d.l	98.55
51	c-28	33.20	b.d.l	b.d.l	13.42	6.30	0.62	19.32	b.d.l	30.03	0.95	b.d.l	b.d.l	103.84
52	c-28	35.01	b.d.l	b.d.l	b.d.l	2.92	0.82	16.72	b.d.l	45.82	b.d.l	b.d.l	b.d.l	101.29
53	c-18	32.38	b.d.l	b.d.l	11.14	1.37	b.d.l	13.85	2.20	38.98	b.d.l	b.d.l	b.d.l	99.92
54	c-18	33.83	b.d.l	b.d.l	9.18	1.87	b.d.l	20.54	b.d.l	39.21	b.d.l	b.d.l	b.d.l	104.63
55	c-18	34.18	b.d.l	b.d.l	8.42	1.84	b.d.l	28.18	1.85	26.87	b.d.l	b.d.l	b.d.l	101.34
56	c-18	33.68	b.d.l	b.d.l	2.41	b.d.l	b.d.l	24.15	b.d.l	39.30	b.d.l	b.d.l	b.d.l	99.54
57	c-18	34.68	b.d.l	b.d.l	8.29	b.d.l	b.d.l	33.37	b.d.l	23.68	b.d.l	b.d.l	b.d.l	100.02
58	c-18	35.01	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	16.60	b.d.l	47.97	b.d.l	b.d.l	b.d.l	99.58
59	c-18	33.00	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	14.86	b.d.l	50.76	b.d.l	b.d.l	b.d.l	98.62
60	c-18	35.40	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	14.49	b.d.l	48.08	b.d.l	b.d.l	b.d.l	97.97
61	c-18	35.86	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	14.60	b.d.l	50.54	b.d.l	b.d.l	b.d.l	101.00
62	c-18	37.04	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	37.14	b.d.l	27.83	b.d.l	b.d.l	b.d.l	102.01
63	c-18	37.19	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	38.63	b.d.l	28.17	b.d.l	b.d.l	b.d.l	103.99
64	c-18	34.31	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	40.79	b.d.l	26.48	b.d.l	b.d.l	b.d.l	101.58
65	c-18	32.14	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	15.85	b.d.l	52.12	b.d.l	b.d.l	b.d.l	100.11
66	c-18	37.03	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	37.87	b.d.l	27.97	b.d.l	b.d.l	b.d.l	102.87
67	c-18	37.67	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	16.46	b.d.l	51.50	b.d.l	b.d.l	b.d.l	105.63
68	c-18	37.30	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	15.37	b.d.l	47.59	b.d.l	b.d.l	b.d.l	100.26

Table A4.6 SEM EDS Analytical report - chromite/magnetite mineral raw data

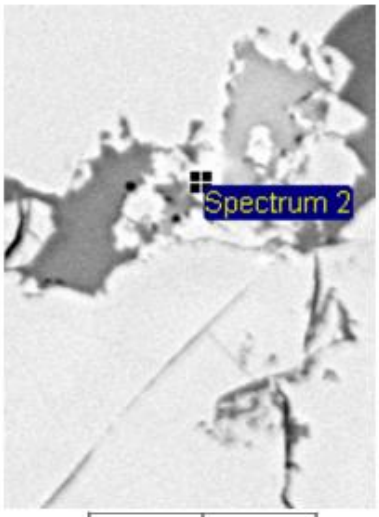
Point_ID	Sample	O K	Ca K	Na K	Mg K	Al K	Ti K	Cr K	Mn K	Fe K	Zn K	S K	Ni K	total
69	c-18	37.26	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	13.79	b.d.l	44.67	b.d.l	b.d.l	b.d.l	95.72
70	c-18	33.44	b.d.l	b.d.l	9.46	1.57	b.d.l	33.84	b.d.l	22.30	b.d.l	b.d.l	b.d.l	100.61
71	c-18	43.96	b.d.l	b.d.l	2.42	2.25	b.d.l	32.09	b.d.l	20.91	b.d.l	b.d.l	b.d.l	101.63
72	c-18	34.97	b.d.l	b.d.l	9.53	3.00	b.d.l	15.94	b.d.l	38.52	b.d.l	b.d.l	b.d.l	101.96
73	c-18	34.56	b.d.l	b.d.l	8.69	3.18	b.d.l	15.25	1.64	40.76	b.d.l	b.d.l	b.d.l	104.08
74	c-18	33.13	b.d.l	b.d.l	2.58	b.d.l	b.d.l	12.95	b.d.l	50.10	b.d.l	b.d.l	b.d.l	98.76
75	c-18	37.37	b.d.l	b.d.l	3.65	b.d.l	b.d.l	15.83	b.d.l	48.63	b.d.l	b.d.l	b.d.l	105.48
76	c-18	34.02	b.d.l	b.d.l	b.d.l	b.d.l	b.d.l	14.61	b.d.l	52.35	b.d.l	b.d.l	b.d.l	100.98
77	c-18	37.16	b.d.l	b.d.l	3.86	b.d.l	b.d.l	18.10	b.d.l	45.80	b.d.l	b.d.l	b.d.l	104.92
78	c-18	35.13	b.d.l	b.d.l	3.60	b.d.l	b.d.l	17.54	b.d.l	40.38	b.d.l	b.d.l	b.d.l	96.65
79	c-18	34.09	b.d.l	b.d.l	3.11	b.d.l	b.d.l	15.16	b.d.l	43.71	b.d.l	b.d.l	b.d.l	96.07

Figure A4.1 Gold-bearing arsenides in association with cobaltite

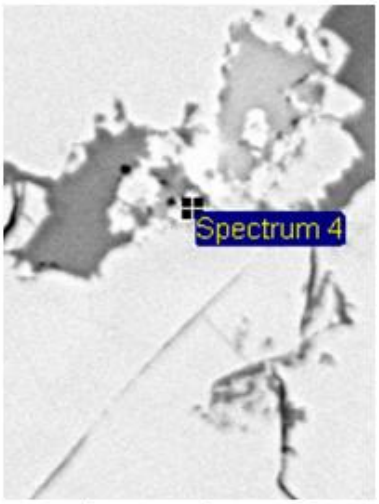




Element	Weight%
S K	20.68
Fe K	5.88
Co K	8.93
Ni K	20.35
As L	44.53
Total	100.38



Element	Weight%
S K	18.13
Mn K	1.33
Fe K	3.29
Co K	12.96
Ni K	3.31
Zn K	5.2
As L	20.45
Ag L	4.24
Au M	28.2
U M	2.6
Total	99.72



Element	Weight%
S K	22.51
Fe K	5.45
Co K	21.6
Ni K	7.35
As L	40.56
Total	97.47

APPENDIX 5. Sulphur isotope analytical data

Ten minerals separated from eight ore samples were selected for sulphur isotope analyses. Samples were sent to the Stable Isotope Ratio Mass Spectrometry (SIRA Lab), Central Science Laboratory, University of Tasmania.

This appendix includes the sampling, analytical techniques and results from the selected samples.

The sulphur isotopic composition is determined by comparing the abundance of naturally occurring isotopes in a sample with a standard. Sulphur has four stable isotopes with the following relative abundances in terrestrial materials (Jager E. and Hunziker, J.C. – 1979):

^{32}S ~ 95%

^{33}S ~ 0.77%

^{34}S ~ 4.2%

^{36}S ~ 0.017%

Because abundance variation from isotopes fraction depends on the relative mass difference, each geologic sample of homogeneous isotopic composition is characterized unequivocally by a single ratio value. The convenient measurement is the ratio between the two most abundant isotopes, $R=^{34}S/^{32}S$. Primary standard is troilite sulphur from the Canon Diablo iron meteorite and it's $R=^{34}S/^{32}S$ is taken as 0.0450045 (or $^{32}S/^{34}S = 22.20$) by convention (Ault and Jensen, 1962).

$$\delta 34S\ (‰) = \frac{\left(\text{R Sample}\ \left(\frac{34S}{32S}\right) - \text{R Standard}\ \left(\frac{34S}{32S}\right)\right)}{\text{R Standard}\ \left(\frac{34S}{32S}\right)} \text{ x } 1{,}000$$

The samples for sulphur isotopes from the study area (10 in total) were crushed in a small jaw crusher followed by hand crushing using pestle to liberate the sulphide grains from the matrix. Minerals were then handpicked using a binocular microscope at Curtin University. Selected grains were collected in vials and sent to University of Tasmania for analyses. The table 01 summarises the visual estimative of contamination by inclusions of other sulphide and sulpharsenide and table A.5.2 contains the analytical results. All results are reported as $\delta^{34}S$ values in parts per thousand (per mil=‰), relative to Canyon Diabolo Troilite (CDT) and analyses were conducted through a conventional techniques for sulphide isotopes based on Robinson and Kasakabe, 1975. In this study, analytical precisions (1σ) are 0.05‰ for the conventional method. All analytical works were completed at the Central Science Laboratory at the University of Tasmania.

Table A5.1 Visual estimate of contamination by inclusion of other sulphides for the samples of the study area

Visual estimate of contamination by inclusion of other sulphides

Sample ID	Mineral	% contamination
C 05	Pyrrhotite	<5
C 08	Chalcopyrite	<10
C 09	Pyrrhotite	<5
C 09	Pentlandite	<15
C 14	Gersdorffite	<5
C 19	Pyrrhotite	<5
C 44	Pyrrhotite	<10
C 44	Pentlandite	<10
C 49	Gersdorffite	<15
C 50	Gersdorffite	<10

Table A5.2 Sulphur isotope data of seven samples selected for sulphur isotopes with ten mineral separates collected. Five were selected from pyrrhotite (3 samples) and pentlandite (2 samples), as they are the most common sulphide mineral from the deposit, two less common and potentially related to later crystallisation of sulphides (one non-magnetic pyrrhotite, one chalcopyrite) and three sulpharsenides (gersdorffite) from the Perseverance deposit (Main ultramafic complex – basal portion). Analysis from the Central Science Laboratory (CSL), University of Tasmania.

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From	Christine Cook, Lab Analyst, SIRA Lab, CSL, University of Tasmania
Date:	18/11/2010

Sulphide for S-Isotope Analysis

CSL No.	Sample ID	Mineral	Weight (mg)	Yield (mmHg)	$\delta\ ^{34}S_{CDT}$ (permil)
12041	C 05	Pyrrhotite	18.6	21.6	**-2.65**
12042	C 08	Chalcopyrite	18.8	27.2	**-3.32**
12043	C 09	Pyrrhotite	19.9	33.2	**-3.76**
12044	C 09	Pentlandite	12.9	14.2	**-3.09**
12045	C 14	Gersdorffite	20.8	18.8	**-3.65**
12046	C 19	Pyrrhotite	21.5	25.2	**-5.00**
12047	C 44	Pyrrhotite	19.9	28.2	**-4.38**
12048	C 44	Pentlandite	14.4	20.4	**-4.13**
12049	C 49	Gersdorffite	20.7	19.2	**-3.10**
12050	C 50	Gersdorffite	20.6	17.8	**-3.31**

Reference: ***Quantitative Preparation of SO_2 for ^{34}S / ^{32}S Analyses from Sulphides by Combustion with Cuprous Oxide.***

Robinson, B.W. and Kasakabe, M., 1975. Anal. Chem.47, 7, 1179-1181.

Overview from Robinson, B.W. and Kasakabe, M., 1975.

Reagent grade cuprous oxide is contaminated with preserving oil and unsuitable for use. However, pure Cu_20 can be made from Analar grade CuO by heating in the furnace tube of a vacuum line. Thus, a temperature of 800ºC and pressure of 10^{-4} bar, for instance, would be suitable for producing cuprous from cupric oxide. Large quantities of Cu_20 should not be made since it may oxidize and/or absorb gases with time.

The sulphide samples are intimately mixed with an excess of Cu_2O and ground to a grain size of about 150µ in a small agate mortar. A burning temperature of 800ºC enhances the life of the furnace windings and 99 to 100% of the theoretical yield of

SO_2 is obtained from Ag_2S within 10 minutes. Difficulties in burning samples such as ZnS (I), PbS, and Sb_2S_3 are overcome by converting them to Ag_2S which also helps to purify mineral samples.

Elemental sulphur samples are reacted with powdered silver in sealed evacuated tubes. $BaSO_4$ samples are converted to Ag_2S by the graphite reduction method. Sulphides such as pyrite may be digested in aqua regia and converted to $BaSO_4$ or burnt directly with Cu_2O. The latter method requires 15 minutes at 1000 ºC to obtain a complete yield of SO_2. Approximately twice the stoichiometric amount of Cu_2O is necessary to avoid incomplete yields of SO_2. This agrees with the 4:1 oxygen to sulphur atomic ratio found to be optimum by Fritz et al.

A few percent of CO_2 is often present in the SO_2. It originates as carbon impurities in the sample and/or absorbed gases on the Cu_20 and sample. The sample Cu_2O mixture can be safely out-gassed above 100 ºC without loss of SO_2. Any CO_2 produced with the SO_2 is most effectively extracted by the use of a η-pentane-liquid nitrogen trap.

APPENDIX 6. Digital copy of dissertation

A digital copy in pdf file format of this dissertation is located on the attached CD.